A MULTI-CRITERIA DECISION SUPPORT FRAMEWORK FOR ENVIRONMENTAL IMPACT AND VULNERABILITY ASSESSMENTS OF OIL ACTIVITIES: A CASE STUDY OF THE NIGER DELTA

OMOLEOMO OLUTOYIN OMO-IRABOR

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I certify that this thesis is the true and accurate version of the thesis approved by the examiners

Signe[redacted]...... Date 16th April 2009
(Director of Studies)

Abstract

The need for an environmental decision support framework that addresses sustainability issues has arisen, due to the long-term environmental and socio-economic neglect of the Niger Delta region, over the last five decades. This research developed a multi-criteria decision support (MCDS) framework for this purpose, using remote sensing data, Geographic Information System (GIS), multi-criteria analysis (MCA) and field survey. A modified Organisation for Economic Co-operation and Development (OECD), Driving Forces-Pressure-State-Impact-Response (DPSIR) conceptual framework was applied in this research.

A review of literature revealed the absence of a multidisciplinary approach, for prioritising areas that have been degraded by oil production and transportation activities. The report first establishes the plausible reasons contributory to the degeneration of the region to its present state, despite existing legislative and regulatory structures by successive governments. This thus established the Driving Forces and Pressures (D&P) attributed to oil exploration, production and transportation activities.

The State (S) of the environment was revealed through a remote sensing methodology. Remote sensing methodology was used to examine, the spatial and temporal landscape changes in the study area. Also the major land cover classes (types) were established, for incorporation in the MCDS framework.

The Impact (I) of oil activities on the ecosystem (especially pathways) was achieved through the analysis of the concentration of elements in soil and water samples collected from spill sites.

The selection of vulnerable sources due to the proximity to oil facilities was achieved by means of Spatial Multi-Criteria Evaluation (SMCE) involving the

application of Multi-Criteria Analysis (MCA), GIS techniques and stakeholder participation

Finally, this research approaches the Response (R) to environmental degradation through the prioritisation of contaminated areas. The involvement of multiple stakeholders with conflicting interests, coupled with the use of sustainability indicators that are intangible in monetary terms, makes the use of the developed framework a transparent and efficient tool for prioritising degraded areas.

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Omoleomo O. Omo-Irabor
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Dedication

To my loving husband, Emmanuel and most cherished children - Peter, Tiyan, Nosa, Osaro and Osas

Conference Papers and Journal Publications (2006-2008)

1 Omo-Irabor O.O., Olobaniyi S.B., Oduyemi K., Akunna J., Venus V., Maina J.M. and Paradzayi, C. 2008. Mangrove vulnerability assessment using satellite images, spatial multi-criteria analysis (SMCA) and GIS techniques. A paper presented at the *7th International Remote Sensing Conference on Application of Earth Observation and Geoinformation for Governance in Africa,* 27-30 October, 2008, Accra, Ghana

2 Omo-Irabor O.O., Oduyemi K., Akunna J. and Ekanem E. 2008. Multi-criteria decision analysis (MCDA) approach to conflict management using of stakeholder participation and Millennium Development Goals (MDGs) agenda. Conference Proceedings of the *1st Postgraduate Researchers' Conference (Postcon2008)*, 29-30 September 2008, University of Abertay, Dundee, United Kingdom

3 Olobaniyi S.B. and Omo-Irabor O.O. 2008. Environmental impact assessment of selected oil production facilities in parts of Niger Delta, Nigeria. Conference Proceedings of the *1st Postgraduate Researchers' Conference (Postcon2008)*, 29-30 September 2008, University of Abertay, Dundee, United Kingdom

4 Paradzayi, C. and Omo-Irabor O. 2008. Mapping Nypa colonization of mangrove environments – Potential for Radar remote sensing in the Niger Delta. Conference Proceedings of the *1st Postgraduate Researchers' Conference (Postcon2008)*, 29-30 September 2008, University of Abertay, Dundee, United Kingdom

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6 Omo-Irabor O.O. and Oduyemi, K. 2007. A Hybrid Image Classification approach for the Systematic analysis of Land cover (LC) Changes in the Niger Delta region. A paper presented at the *5th International Symposium on Spatial Data Quality (ISSDQ)*, 13-15 June, 2007, ITC, Enschede, Netherlands

7 Omo-Irabor O.O. and Oduyemi, K. 2006. A comparative Study of Classification Methods for monitoring Land use/Land cover changes using remote sensing and GIS Techniques. A paper presented at *the 6th International Conference on Earth Observation and Geoinformation Sciences in Support of Africa's Development*, 30 October-2 November, 2006, Cairo, Egypt.

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Chapter 1 : General Introduction

1.1 Introduction

Industrialization can positively transform societies by providing a better quality of life and promoting economic growth. However, the quest to attain such status can also negatively impact societies through environmental degradation. Environmental degradation and its effects on humans and the ecosystem are of global concern (Shinsato, 2005). By every indication, the environment is the life wire of any given society because it provides habitation and means of survival for the local populations and fauna (Nasong'o and Gabsa, 2000). For most environmental issues, the necessary database to produce an action plan or policy for environmental impact assessment is not sufficiently developed, and the challenge is often to complement existing information with well chosen measures (Walker, 2001). This normally involves identifying goals and assessment endpoints, preparing a conceptual framework, and developing a plan of analysis.

1.2 Environmental Impact Assessment (EIA)

Environmental Impact Assessment (EIA) was developed and introduced in the 1960s as a tool to improve and involve the public in decision making (Kværner et al., 2006). It is an ideal anticipatory mechanism, which establishes qualitative and/or quantitative values for parameters indicating the quality of environment before, during, and after the proposed developmental activity, thus allowing measures that ensure environmental sustainability (Goyal and Deshpande, 2001). The effectiveness of EIA has been a subject of research for sometime (Kauppinen et al., 2006).

Impact assessment relates to a process rather than a particular activity (Giupponi et al., 2006). According to Kennedy (1988); in (Wathem, 1992), EIA is used in relation to two principal functions;

- as a *planning tool* to minimise adverse impacts caused by a development activity; emphasis is on the methodologies and techniques for identifying, predicting and evaluating the environmental impacts of a proposed project or programme
- as a *decision making instrument* to decide upon the acceptability of a development activity based on its environmental costs and benefits. It enables appropriate authorities to make a decision with regards to a proposed project or activity.

The need to make decisions based on environmental impact assessment (EIA) is becoming increasingly important, yet a few people have the tools or knowledge to understand or appreciate them in their complexity (Chechile, 1991, Cortes et al., 2001, Costi et al., 2004). The multidimensional nature of EIA also compounds the problem, being especially troublesome when intuition alone cannot help us determine which of several outcome is the most desirable, or the least objectionable, and neither logic or intuition is of help (Saaty, 1980, Bell et al., 2003). Hence the necessity for a multi-criteria framework, that addresses the different attributes and is also responsive to the issues being addressed.

1.3 The Concept of Environmental Vulnerability Assessment

The concept of vulnerability originates in research communities examining risks and hazards, climate impacts and resilience (Turner et al., 2001). It has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to enhance well-being through reduction of risk (Adger, 2006). Many definitions of core concepts exist, but there is no consensus on their meaning. This diversity, and sometimes the incompatibility among different uses of terms, are largely explained by established discourse frames and patterns characterising the distinct research communities from which the concepts originate (Maxim and Spangenberg, 2006). The concept of vulnerability can be defined as "the degree of loss to a given element at risk (or set of elements) resulting from a given hazard at a given severity level" (Coburn et al., 1994). Vulnerability assessments measure the seriousness of potential threats (Diop, 2003).

The vulnerability assessment can be used as a basis for planning, and allocation of resources, to cope with both endemic oil pollution and to promote an effective response to a potential major event (Catto and Etheridge, 2006). Furthermore, policy makers and managers require objective, scientific and accurate evidence in order to make difficult choices and decisions. The use of vulnerability assessment in policy making ranges from advising decision makers of the need for or consequences of their actions, to providing direction for the allocation of resources, to informing decisions about land use activities, to educating the general public about contamination potential (Fussel, 2007, Gallopin, 2006, Luers, 2005, Metzger et al., 2005, National Research Council, 1993, Research and Assessment Systems for Sustainability Program, 2001, Schröter et al., 2004, Villa and McLeod, 2002).

1.4 The need for a Multi-Criteria Environmental Decision Support Framework

Decisions are important not only because they are at the origin of environmental problems, but also because they are at the core of solutions to these problems. Therefore, decision support framework to aid environmental decision making is essential for both understanding and dealing with environmental issues.

When resources for revenue generation are in short supply, societal pressures, particularly in relation to land utilization become increasingly higher (Pollard et al., 2004). The need for socio-economic and environmentally sustainable development practices and policies then become a major focus for community development planning (Ikein, 2004). The absence of a universally accepted management framework able to meet the needs of all concerned parties can pose a problem. This is particularly true for environmental planning and management of natural resources, such as crude oil production especially in developing countries of the world. The complexity of environmental problems make necessary the development and application of new tools capable of processing not only numerical aspects, but also experience from experts and wide public participation, all which are needed in decision making processes (Poch et al., 2002). Where there is a mutually acceptable framework, then there exists the possibility that sustainable development can be attained to the common satisfaction of all parties involved (Ikein, 2004). Such a framework will be beneficial to policy and decision makers in government and private organisations (end users of the framework). Also, the framework will be beneficial to other stakeholders (host community members) affected by the decision outcome. Host community members as applied in the work, are individuals who reside in areas where projects and industries are sited and they are positively or negatively affected by their presence.

The long period of oil exploration and production in the Niger Delta region under irresponsive and dictatorial governance, coupled with the prolonged absence of adequate policies to address the environmental impact, has resulted in massive disinvestment in human capital, culminating in high unemployment among the youths. This in turn has bred a frustrated population culminating into conflicts, hostility, and agitation for regional resource control. Therefore, there is need for decision makers in the region to widen their perspective and embrace formal and integrated tools for achieving a balance of combining economic, social and environmental criteria when dealing with environmental degradation resulting from oil activities. Thus, this requires a comprehensive, integrated approach to decision making that helps people structure these complex problems in a framework that takes advantage of the best scientific knowledge where this exists, and capitalises on the knowledge and experience of local experts and the participation of host communities (Itami et al., 2000).

1.5 Research Aim and Objectives

The aim and objectives of the PhD research are as follows:

Aim

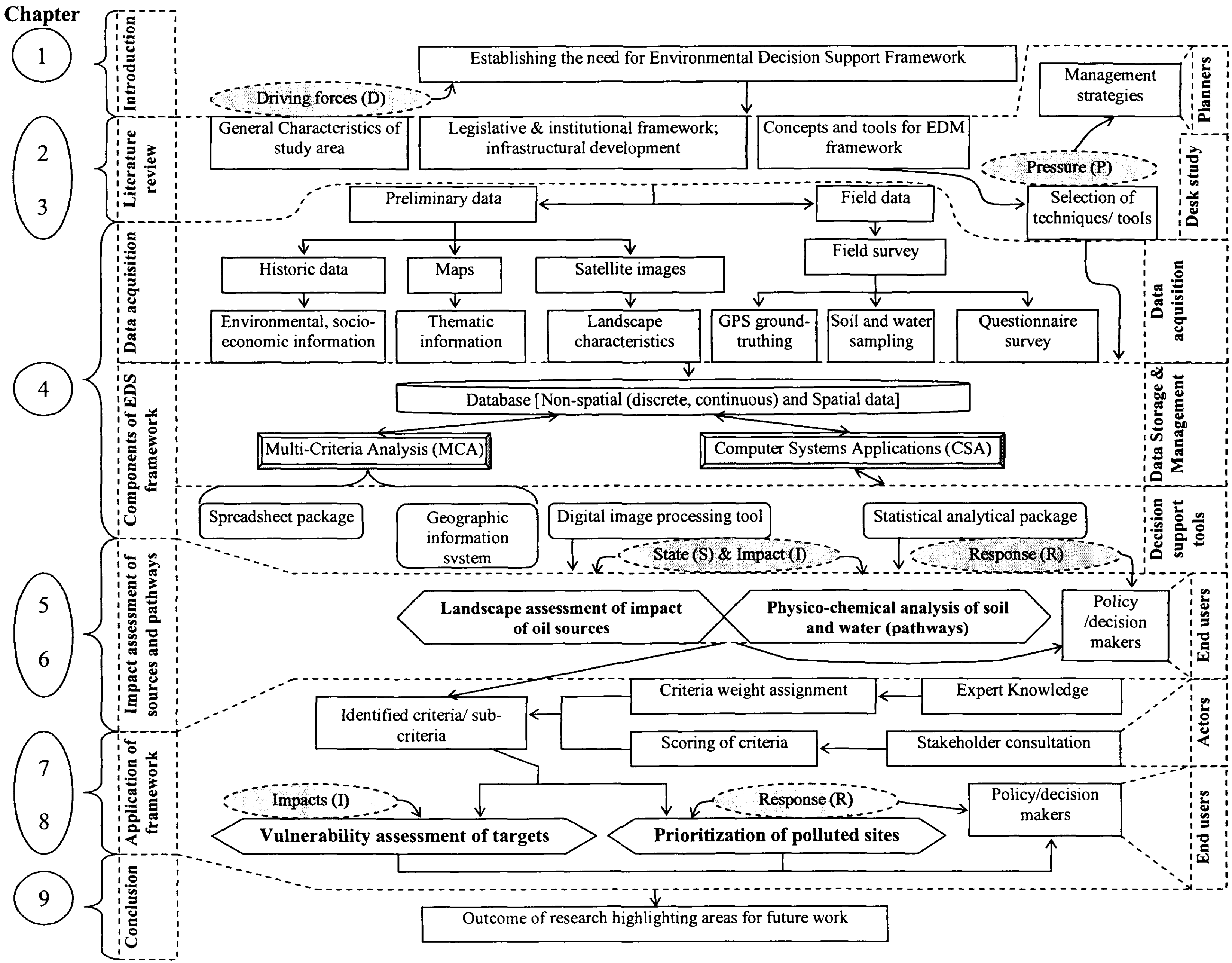
The aim of this research is to develop and test a decision support framework for environmental impact and vulnerability assessment of oil exploration activities. This involves a sustainability approach that takes cognisance of environmental, social and economic indicators for prioritising environmentally degraded areas resulting from oil activities in the Niger Delta, by the integration of field survey data and remotely sensed data with the aid of multi-criteria analysis (MCA) and GIS techniques. The framework will also be used as a decision making tool that would assist in proffering solutions to the unending crisis in the Niger Delta, so as to allow for sustainable environmental and socio-economic development in the region. The strategies for achieving this aim, is shown in Figure 1.1.

Objectives

To achieve the aim of this research, the following objectives will be executed:

- A review of existing literature to identify the gaps in knowledge hindering sustainable development in the region thereby establishing the need for this research
- Examine environmental decision making concepts/tools and develop a decision support framework
- Undertake landscape assessment of the region using remote sensing methodology for incorporation in the decision support framework
- Investigate the nature and sources of pollution to aid in prioritising degraded areas
- Identify and weigh criteria for environmental vulnerability assessment of the ecosystem
- Evaluate and validate the framework for prioritising contaminated sites.

Figure 1.1: Flowchart for achieving the aim and objectives of research work



1.6 Justification of the Research

The long term neglect of the Niger Delta by successive governments and oil companies has led to severe environmental degradation, economic deprivation and social exclusion in the oil rich region. The intervention strategies by government have so far failed to address the particular needs of the people. There exist to date no framework that aids in prioritising areas at risk to pollution from petroleum and its derivatives, or vulnerable due to the long period of socio-economic neglect. This is essential when financial resources available for executing conservation plan are limited. A study undertaken by the World Bank (1999) ranked environmental issues of the Niger Delta, using an analytical framework that focused on environmental, human health significance and intervention benefits. Surprisingly, available scientific evidence ranked environmental pollution as having a low overall priority. This is as a result of the fact that the environmental issues were aggregated and approached from a regional level, thus subduing the significance of pollution. The report highlighted that such results may conflict with perceptions of local communities whose lives are directly affected by the problem.

UNDP (2006) took a human development approach to the situation in the Niger Delta using income, education and life expectancy as indicators to measure various aspects of socio-economic progress and human advancement. This approach questions the presumption of an automatic link between expanding income and expanding human choices, and places people at the centre of development.

Based on the afore-mentioned, it can be seen that prioritising areas degraded from prolonged oil activities from a sustainability point of view, has not been addressed so far in the Niger Delta region. This research therefore attempts to utilize field survey, remote sensing data, GIS techniques, and multi-criteria analysis for environmental impact and vulnerability assessments to aid in the prioritization of contaminated areas.

The use of remote sensing data to detect the different land cover types, in conjunction with thematic data on oil facilities and stakeholder involvement to obtain vulnerable areas is a novel approach in environmental assessment studies. Furthermore the application of the MCDS framework for prioritising contaminated/degraded areas using indicators for sustainable development has not been attempted in the region. Finally, the framework presents a multidisciplinary approach in combination with multi-criteria analysis (MCA) for prioritising these areas. The dearth of relevant data/information has created the need to utilize primary data obtained from expert knowledge and stakeholders in environmental assessment and management issues.

1.7 Structure of PhD thesis

This section of the thesis deals with the overall structure of the research work. The work addresses one major issue, i.e. developing a multi-criteria decision support framework for environmental assessment of oil activities. The thesis has therefore been structured as presented in Table 1.1 and Figure 1.1.

Table 1.1: Structure of PhD thesis

Chapter	Title	Description/Activity
1	General introduction	Background information on the research work. The need for decision support framework is mentioned and justification for the research is highlighted.
2	Literature review – Part I	General characteristics of the Niger Delta region. Legislative and institutional framework; and infrastructural development by government. A critical attempt is made on plausible reasons for the region degeneration to the present state despite existing legislative and regulatory structures by successive government.
3	Literature review – Part II	Concepts and tools applied in the development and application of decision support framework.

Chapter	Title	Description/Activity
4	Data acquisition and components of multi-criteria decision support (MCDS) framework	Data acquired and components of MCDS framework. Processes in the development of multi-criteria decision support tool for environmental impact assessment are also addressed.
5	Landscape assessment using remote sensing methodology	Digital image processing for the derivation of landscape data from satellite images.
6	Physico-chemical characterization of pathways (soil and water quality assessment)	Impact assessment of contaminants using physico-chemical constituents of major pathways (soil and water) through univariate and multivariate statistical analytical approaches.
7	Environmental vulnerability assessment	Vulnerability assessment of possible targets using multi-criteria analysis (MCA)
8	Application of framework Prioritization of contaminated sites	Application of MCDS framework for prioritizing contaminated sites
9	Conclusion and recommendations for further research	Conclusion of the research work including limitations and recommendations for future research studies

Chapter 2 : Literature Review – Part I (Introduction on the Niger Delta Region)

2.1 Introduction

In the last forty years, the Niger Delta region has been the focus of oil exploration and exploitation activities. The situation in the region has become prominent due to the degree of devastation and unrest, also partially putting pressure on the increase in international crude oil market prices in the last two years. The oil and gas phenomenon ranging from exploration to production has been a highly sensitive issue attracting global attention (Tolulope, 2004). In Nigeria, the oil and gas industry is the most important sector of the national economy with an estimated 25 billion barrels and 130 trillion cubic feet of crude oil and gas reserves respectively (Chokor, 2004). According to Oil and Gas Journal, (2006) Nigeria had 36.2 billion barrels of proven oil reserves and an estimated 182 trillion cubic feet (Tcf) of proven natural gas reserves as of January 2007.

This chapter provides an insight into the general setting of the Niger Delta, focussing on the environmental issues responsible for the present state of the region.

2.2 General Characteristics of the Niger Delta Region

2.2.1 Physical environment

Delta State which was selected for this study as shown in Figure 2.1, is located in Niger Delta region. It is bounded in the North by Edo State, on the East by Anambra State, on the South-East by Bayelsa State, and on the Southern flank is the Bight of Benin which covers approximately 160 km of the State's coastline and a landmass of about 18,050 km^2 of which more than 60% is land. The State produces about 30% of crude oil from onshore/offshore and natural gas in Nigeria. Other natural resources include rubber, oil palm, silica, industrial clay, kaolin, assorted fruits and timber.

The selection of the region for this study was based on the following reasons:

(1) Oil and gas exploration and production activities are prominent making the petroleum industry the major source of revenue for the state and the Country at large.

(2) The region contains sensitive biodiversity areas with high marine biodiversity and critical habitats, particularly the mangrove habitat.

(3) The region is an area valued and used by diverse overlapping interests groups, including agricultural activities, commercial fishing, marine transportation, research, and structural development.

(4) Although the Niger Delta is one of the least developed regions of Nigeria, it is expected to undergo significant future population growth since the present government has now concentrated efforts to redressing the backwardness in development.

Therefore these conditions are ideal for developing a decision support framework to identify the most suitable location where rehabilitation and/or developmental efforts should commence.

The region is a delta with a vast floodplain built up from the accumulation of sedimentary deposits from rivers Niger and Benue (Rim-Rukeh et al., 2007). Being a vast interface between land and water systems, it is ecologically very complex (Sokari-George, 1989). Due to the high rainfall (average annual of 3000mm), flat terrain and poorly drained sediments, a dynamic equilibrium exists between flooding, erosion and sediment deposition. The study area lies in the wet equatorial climatic region with mean daily temperature of 26°C. It is also characterized by high cloud cover and relative humidity of 78.5% for Warri (SPDC., 2006).

The pristine vegetation has been reduced considerably in the area and replaced by mosaic of secondary re-growth such as arable farmlands (cassava, maize, yam) and tree crops (oil palm, rubber, cocoa, plantain) (Osuji and Onojake, 2006). The remaining natural vegetation still occur as fresh water swamp forest, mangrove swamp forest and ever green lowland rainforest a major source of timber.

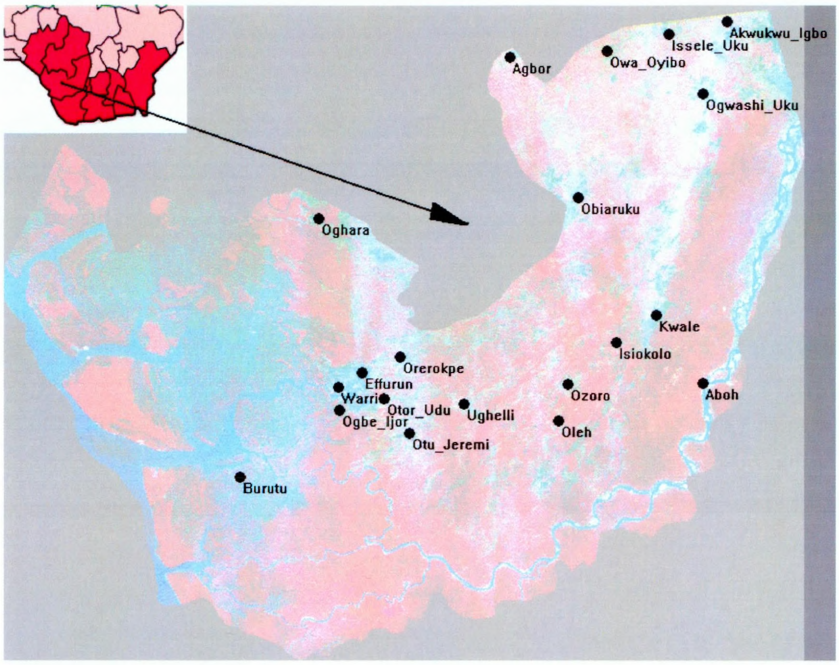


Figure 2.1: False colour composite image of Delta State with sampled Local Government Areas (LGAs) headquarters (insert Niger Delta region in red)

The River Niger is the major drainage system from which other discrete river systems originate which creates a condition of delta-wide hydrological continuity (Abam, 2001). It is one of the World's largest Tertiary delta systems and an extremely prolific hydrocarbon province (Doust, 1990, Chukwu, 1991). The region is responsible for over 90% of oil exploration and development activities in Nigeria (ANEEJ, 2004); therefore a review of its geological setting is necessary.

The Niger Delta basin is situated in the Gulf of Guinea, formed at the site of a rift triple junction related to the opening of the southern Atlantic starting in the Late Jurassic and continuing into the Cetaceous (Michele *et al*, 1999). It covers an area of about 75,000 sq km with a clastic sequence which reaches a maximum thickness of 9,000 – 12,000m of sediments (Sonibare and Ekweozor, 2004). Five main surface geological units have been identified, consisting of: Alluvium, Coastal

Plains Sands, Mangrove swamps, Sombreiro Deltaic Plain and Abandoned Beach Ridges. Its subsurface geology is presented in Figure 2.2 and reveals a three-fold lithostratigraphic subdivision, comprising an upper sandy Benin Formation, an intervening unit of alternating sandstone and shale named the Agbada formation, and a lower shaly Akata formation (Ophori, 2007). These three units extend across the whole delta and each ranges in age from early Tertiary to Recent (Reijers et al., 1996, Sonibare and Ekweozor, 2004).

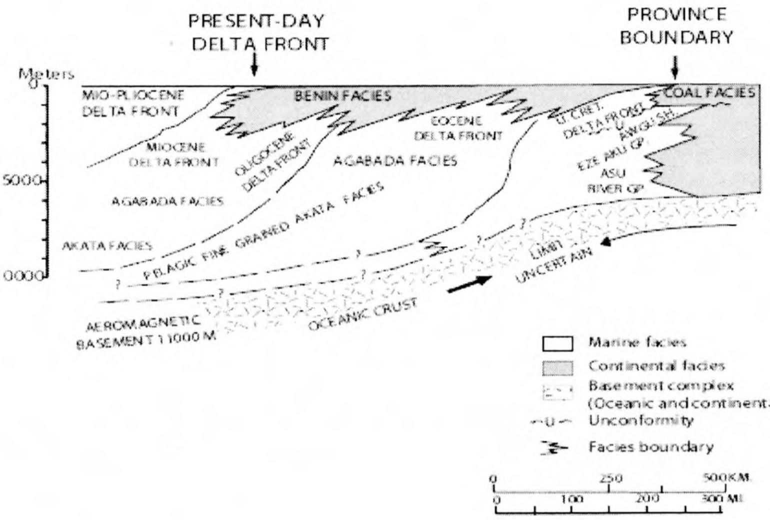


Figure 2.2: **Cross section southwest-northeast through the Niger Delta (Tuttle et al., 1999)**

Petroleum occurs throughout the Agbada Formation of the Niger Delta, however, several directional trends form an "oil-rich belt" having the largest field and lowest gas:oil ratio (Tuttle et al., 1999). The belt extends from the northwest offshore area to the southeast offshore and along a number of north-south trends in the area of Port Harcourt as displayed in Figure 2.3. This hydrocarbon distribution was originally attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil). Ejedawe (1981) in (Tuttle et al., 1999) stated that the two controlling factors are an increase in geothermal gradient relative to the minimum gradient in the delta centre and the generally greater age of sediments within the belt relative to those further seaward.

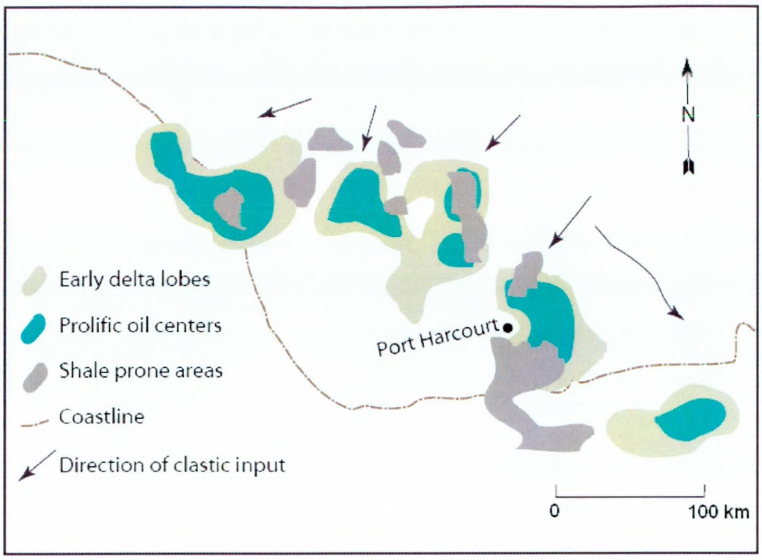


Figure 2.3: Location of lobes of the early Niger Delta, prolific oil centres, and shale prone areas (Michelle, 1999)

It is imperative to note that the physical environment of the selected study area for this research is strategically located in terms of having very prolific oil centres thus being one of the highest producers of crude oil in the country.

2.2.2 Social environment

Delta State was created on 27 August, 1991 from the defunct Bendel State and presently the State is made up of 25 Local Government Areas and 149 communities. Its population is estimated to be 4,098,391 in 2007 (Federal Republic of Nigeria, 2007). The major tribes in the State are Urhobo, Ijaw, Isoko, Ibo and Itsekiri. The Ijaws, which are the largest are said to be the oldest settlers in the region, have numerous clans each of which has linguistic and cultural distinctiveness (ANEEJ, 2004). According to Federal Republic of Nigeria (2007) in Madu (2008), the total population of the Niger Delta region is 31,224,577, indicating that the population of the region is significant in comparison with the total population of Nigeria.

Table 2.1: Population of States in the Niger Delta region (Madu, 2008)

State	Population
Abia	2,833,999
Akwa Ibom	3,920,208
Bayelsa	1,703,358
Cross River	2,888,966
Delta	4,098,391
Edo	3,218,332
Imo	3,934,899
Ondo	3,441,024
Rivers	5,185,400
Total	31,224,577

About 80% of the population is engaged in farming, fishing and hunting, which are the major occupations of the inhabitants of Delta State, with the remaining 20% engaged in other occupations. The major human activities in the region can be classified into three types; traditional primary activities such as farming, fishing and lumbering. Secondary activities include manufacturing, oil refining and various traditional industrial activities (weaving, carving, dyeing, smithing). Tertiary activities include commerce, administration, banking and finance, information, transportation and local traditional marketing (Niger Delta Environmental Survey, 1997). This shows the predominance of the traditional sector and hence the importance of the environmental media to the livelihood of the populace.

2.3 Legislative and Institutional Frameworks

This section addresses global evolution of environmental issues; special emphasis is placed on policies, environmental laws, institutional and infrastructural organisations in Nigeria. The recurring problem of environmental pollution, despite the legislative and institutional framework already in existence to tackle such issues is also dealt with.

2.3.1 Evolution of environmental policies

In the 1960s, there was a resurgent of environmentalism. However, the resurgence was limited to the industrialized countries (Pearce and Turner, 1990). In 1969, the United States, due to the concern over environmental degradation passed the first legislation for Environmental Impact Assessment (EIA) called the National Environmental Policy Act (NEPA). This was subsequently signed into law by President Richard Mihous Nixon in 1970. By the same year, the Environmental Protection Agency (EPA) was created in the US with a mission to protect human health and the environment (Russo, 2002, USEPA, 2007). The goal of USEPA was to prevent pollution wherever possible and to reduce risk for people and ecosystems in the most cost-effective ways possible (Russo, 2002). Other countries such as, Australia, Canada, New Zealand, Colombia, Thailand and West Germany soon introduced EIA provisions as part of their training process. In 1974, the Organisation for Economic Corporation and Development (OECD) recommended that member government adopt EIA procedures and methods, and more recently, that they use EIA in the process of granting aid to developing countries (Wood, 2003). In 1989, the World Bank ruled that EIA for major projects should be undertaken by the borrower country under the Bank's supervision. The United Nations Environment Programme (UNEP) also made recommendations to member states regarding the establishment of EIA procedures and established goals and principles for EIA.

The Environment Agency (EA) is the principal environmental protection regulator for England and Wales (Wood, 2003). A generic model of the EIA process includes such distinct stages as screening, scoping, impact prediction and evaluation, mitigation, reporting, decision-making, and post-project monitoring and evaluation (EIA follow-up), with public participation and consideration of alternatives potentially incorporated at all stages of the process (Demidova and Cherp, 2005).

In Scotland, the Scottish Environment Protection Agency (SEPA) has the environmental responsibility of executing EIA (Scottish Statutory Instruments, 1999). The organisation works in accordance with the European Union (EU) Directive and the 1999 Regulations. EIAs are required for certain developments, which are either to be carried out in sensitive areas, or that satisfy a threshold or criterion.

In order to protect the environment and the oil prospecting areas, the Federal Government of Nigeria (FGN) enacted various policies, decrees and laws that guide the operation and activities of the oil and gas companies (Taiwo, 2003). An analysis by Ogunba (2004), showed that the initial focus of environmental awareness and legislation in Nigeria was on the petroleum industry, which came in the form of pollution reduction measures in reaction to local problems within the petroleum industry. Environmental awareness continued to grow with the country's participation in international environment conferences, such as the United Nations 1972 Stockholm Conference, which addressed problems of the human environment. In Nigeria the first seminar on environmental pollution from oil activities was held in 1979 in Port - Harcourt. Since then there has been growing public and government concern about the pollution of the Nigerian environment.

Legislation relating to environmental matters in Nigeria has over the last three decades been strongly influenced by the style practiced in Europe and the United states (Edoho and Dibie, 2000). The authors have observed that the lukewarm attitude towards environmental policies in Nigeria stems partly from the fact that governments cannot claim a bonafide ownership of environmental policies.

The principal premise upon which this environmental style was based was founded on the supposition that significant incentives to the industrial sector through the use of modern technology would bring about a highly dynamic increase in all productive activities and this would in turn propagate technological progress throughout the economy (Edoho and Dibie, 2000). The authors further noted that such a modernization process was expected to raise the qualifications of both labour and management, thereby leading to new and highly productive investment as well as environmental conditions. In turn, the incorporation of advanced technology would permit future development of domestic technology, which would promote self-sustained development. The problems in the adopted style are reflected in the poor social and economic conditions that prevail in both the rural and urban areas (Edoho and Dibie, 2000).

It is therefore worthy to note that the decision support framework being proposed in this research work will be capable of providing information to policy makers on areas that require improvement in the environmental and socio-economic status. This would be achieved by involving the different stakeholders in oil related activities, thus promoting transparency and sustainable development in the region.

2.3.2 Environmental laws

The exploration for oil in the Niger Delta region, led to the passing of legislations to control various petroleum activities in the country. The government sought to achieve this goal through the various petroleum laws and regulations, for the protection of the environment from oil and gas pollution. An overview of the existing environmental laws in Nigeria indicates that the laws can be classified into two distinct groups: pre-1988 and post-1988 (Akpofure and Ojile, 1999).

(i) Petroleum Act (1969)

Several regulations were promulgated under the Petroleum Act, 1969 to regulate the exploration of petroleum in Nigeria, and control pollution. Under the Petroleum Act 1969, the entire ownership and control of all oil and gas in place within any land in Nigeria, under its territorial waters and continental shelf is vested in the state of Nigeria. The regulations were more seen to be reactive than proactive (Ogunba, 2004), meaning that the former only identified local problem and prescribed solutions addressed through negotiation between government officials and the polluters as against proactive impact identification and mitigation which is achieved through impact assessment and project approval/licensing.

(ii) The Land Use Act (1978)

Land ownership in Nigeria is subject to a range of diverse cultural and traditional practices and customs. The Land Use Act of 1978 is mentioned because its implementation can be linked to the present state of Niger Delta region. Under the traditional system of ownership, people were guaranteed land for all necessary purposes. However, this stable system has been distorted by the introduction of legal instruments within the body polity of the modern nation-state.

Under the Land Use Act, the ownership of land is vested in the Federal Government, but provisions in the Act make it possible for State and Local Governments to hold the land in their respective areas in trust. This has deprived or rendered communities landless in terms of economic rent, environmental degradation in the form of oil pollution and the attendant monetary compensations accruing from these (Akpofure and Ojile, 1999).

Critics of the Land Use Act have pointed out that the interests of individuals and communities have been reduced to mere rights of occupancy, which can be revoked by the appropriate authorities on certain conditions such as 'over-riding public interest' (way-leaves, prospecting for oil, mining activities, or oil pipelines). Moreover, the law is ambiguous in certain respects and makes interpretation difficult. The Act grants excessive powers to the Federal and State Governments, which have a dramatic impact on land rights. It does not provide adequate security against forced evictions, harassment, and threats.

(iii) Federal Environmental Protection Agency Act (1988)

The following regulations were made under the FEPA Act. They include

- National Environmental Protection (Effluent Limitation) regulation
- National Environmental Protection (Pollution Abatement in Industries and Facilities Generating Wastes) regulations and
- National Environmental Protection (Management of Solid and Hazardous Wastes) regulations

(iv) Environmental Impact Assessment Act (1992)

Environmental impact assessment is evolving worldwide, however the practice is not even across different countries (Glasson et al. 2005). The situation in Africa is changing rapidly, with many countries such as Nigeria instituting EIA regulations. This development has been influenced by a range of initiatives such as the 1995 African Ministerial Conference on Environment. In Nigeria, the Act was enacted in 1992, by Decree 86 (Adegoroye, 1994, Adomokai and Sheate, 2004). The Environmental Impact Assessment (EIA) Act reaffirmed the powers of the FEPA and defined the minimum requirements for an EIA. But it has been argued that the law fails to protect the rights of people who may face eviction as a result of a particular project, in spite of the fact that this is an internationally recognised procedure.

The EIA Act empowers the FEPA to ensure the implementation of mitigation measures and follow-up programmes such as the elimination, reduction, or control of the adverse environmental effects of any project; the restitution of any damage caused by such effects, through replacement, restoration, compensation or any other means; verification of the accuracy of the environmental assessment of a project; and determination of the effectiveness of any measures taken to mitigate the adverse effects of any project.

(v) The Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) (2002)

EGASPIN is published by the Department of Petroleum Resources (DPR) (EGASPIN, 2002). It was issued to regulate the impact of specific industries (e.g. the oil and gas industry) on the environment (Ayanbule and Makinde, 2006). DPR through EGASPIN provides permits for all aspects of oil-related effluent discharges from point sources (gaseous, liquid and solid), and oil-related project development. EGASPIN also contains a list of activities in the oil and gas sector that require environmental assessment.

(vi) Other Environmental Laws

The Petroleum Inspectorate under the umbrella of DPR is principally responsible for the enforcement of the following Acts and regulations.

(a) Petroleum Regulation 1967,

(b) Oil in Navigable Waters Act 1968,

(c) Oil in Navigable Waters Regulation 1968

(d) Petroleum (Drilling & Production) Regulations 1969,

(e) Petroleum (Drilling & production) Amendment Regulations 1973,

(f) Petroleum Refining Regulations 1974; and

(g) Oil Pipelines Act 1990.

These Acts and Regulations were designed to prohibit or control the pollution of water, air and land and also prescribe sanctions in the form of fines, imprisonment or damages to be enforced against persons or companies who infringe the provisions. Despite these laws, World Bank, (1995) noted that the principal constraints to addressing environmental concerns in the Niger Delta region include: institutional capacity, information, regulatory framework and enforcement.

2.3.3 Institutional regulatory framework

The thrust and direction of the government regulatory presence is shaped to a certain extent by the structure of the agencies carrying out these activities (Gute, 1991). Each governmental entity brings to task a specific mandate and set of perceived responsibilities. In Nigeria the first environmental regulatory body concerned with petroleum matters, was the Department of Petroleum Resources (DPR). Created in 1969 under the Ministry of Petroleum Resources it is the regulatory arm of the Nigerian National Petroleum Corporation (NNPC). In the absence of an independent Petroleum Inspectorate, DPR was also vested with the authority of the Petroleum Inspectorate. Its role includes the setting of standards for the effective control of the oil and gas industries. The department also has the following responsibilities:

- Ensuring compliance with all Petroleum laws and regulations
- Encouraging full development of Nigeria's petroleum resources

- Ensuring the protection of all investments (foreign and local, public and private)
- Monitoring of companies' operations to ensure safe environmental practices, while ensuring harmonious and cordial relationship between the companies and the communities.
- Promoting intra-industry peace

Following the disclosure of toxic waste dumped at Koko, a port in the Niger Delta region in June 1988, the government of Nigeria established by Decree 58 of December 30, 1988, the Federal Environmental Protection Agency (FEPA) as an autonomous body with the overall responsibility of protecting the Nigerian environment (Echefu and Akpofure, 1999, Ogunba, 2004). The promulgation of FEPA Decree marked the most significant beginning of general legislation pertaining to environmental issues (Niger Delta Environmental Survey, 1997). Its duties included the management and monitoring of environmental standards; devising policies for the protection of the environment (biodiversity, conservation); the sustainable development of Nigeria's natural resources; and the development and operation of procedures for conducting environmental-impact assessments of all development projects.

In 1989, the Federal Government of Nigeria Published the National Policy on the Environment (NPE) to emphasize its commitment to sustainable development (Areola, 1998). This was to enhance the work of FEPA. The policy was aimed at fixing previous damage to the environment through decades of uncontrolled exploitation of natural resources and to initiate and ensure conservation measures that are relevant for the protection and preservation of the ecosystem. The basis of environmental policy in Nigeria can be found in Section 20 of the 1999 Constitution of the Federal Republic of Nigeria which contains provisions for the protection and improvement of the environment and safeguarding of water, air and land, forest and wildlife of Nigeria (Ayanbule and Makinde, 2006). FEPA had the following goals and objectives.

1. Establish adequate environmental standards, and monitor and evaluate changes in the environment
2. Publish and disseminate relevant environmental data including an annual "State of the environment" report.
3. Require the prior environmental assessment of proposed activities, which may affect the environment or use of natural resources.
4. Establish facilities and infrastructure for pursuing and prosecuting the national environmental policy goals, objective and standards.

The goals of the National Policy on the Environment are expressed in the following five points.

1. Secure for all Nigerians a quality of environment adequate for their health and well-being;
2. Conserve and use the environment and natural resources for the benefit of present and future generations;
3. Restore, maintain and enhance the ecosystems and ecological processes essential for the functioning of the biosphere to preserve biological diversity and the principle of optimum sustainable yield in the use of living natural resources and ecosystem
4. Raise public awareness and promote understanding of essential linkages between environment and development and to encourage individual and community participation in environmental improvement efforts; and co-operate with other countries, international organisations/agencies to achieve optimal use of transboundary natural resources and effective prevention or abatement of transboundary environmental pollution (JICA, 1999).

In order to give environmental issues greater consideration, the Federal Ministry of Environment (FMEn) was established in 1999, to co-ordinate various environmental matters and tackle environmental degradation issues vigorously. It absorbed the functions of FEPA and departments related to the environment of other ministries. Notable programmes currently undertaken are in erosion control, forestry development, desertification control and inventory of impacted solid minerals mining for ecosystems rehabilitation.

In a proactive move to checkmate the related scourge of oil spill, the Ministry constituted the "Forum for Cleaning the Niger Delta" involving all the relevant stakeholders, especially the communities. This resulted in the approval of a National Oil Spill Contingency plan for Nigeria in compliance with the International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC) of 1990 (Baker, 1991). To manage this contingency plan and superintend Government's efforts at containing related environmental problems, the National Oil Spill Detection and Response Agency (NOSDRA) was also approved.

In spite of these efforts, it has been argued that 'Nigeria continues to face critical environmental problems that should be promptly addressed'. Following the establishment of the FMEn in 1999, the Environmental Policy was reviewed, although this has not yielded the desired results. This failure is ascribed to weak enforcement of the law; inadequate manpower in the area of integrated environment management; insufficient political will; inadequate and mismanaged funding; a low degree of public awareness of environmental issues; and a top–down approach to the planning and implementation of environmental programmes (Ogunba, 2004). The major problem in the enforcement of the laws as highlighted by Adegoroye (1994) and Ebeku (2005), is the dual role played by the federal government as operator and regulator.

2.4 Government Infrastructural Development Efforts

The environmental laws outlined in section 2.3.2 were first promulgated in the late 1960s by that time the oil companies had long been in operation in the Niger Delta region. In a bid to suppress the environmental insecurities and ecological impacts of oil activities, the Federal Government of Nigeria, made the first major attempt to address development plans in the region was in 1957, when the colonial administration set up the Willink's Commission of Inquiry to investigate the fears of minorities and how to allay them. The Commission's report led to the setting up of the Niger Delta Development Board (NDDB) in 1961 (UNDP, 2006). Subsequent bodies included the Niger Delta Basin Development Authority (NDBDA) set up in 1976, and the Oil Mineral Producing Areas Development Commission (OMPADEC) set up in 1992. From the onset, these institutions were beset by a number of problems including those of legitimacy and transparency (NDDC). When the present federal administration, headed by President Olusegun Obasanjo came into power in 1999, it constituted a new body, the Niger Delta Development Commission (NDDC) to take over from OMPADEC. The establishment of NDDC and its predecessor development agencies were all directed to reverse the negative trends of underdevelopment and create the means to attain sustainable development in the Niger Delta (Ikein, 2004). In spite of the provisions of the NDDC Act on financing, the NDDC is facing some of the same problems with funding that plagued OMPADEC (Uwem, 2007).

Among the mandates of the NDDC is the execution of projects in the Niger Delta region. Projects are expected to be conceptualized, designed and executed based on extensive consultation with locals, input from interested parties and critical analysis by experts (NDDC, 2008). Where limited funds exists and with a number of projects to be executed, a decision support framework as developed in this thesis will not only provide a credible method for selecting appropriate infrastructures, but it will also highlight areas of high priority. Government organisations such as NDDC could benefit from decision outcome of the framework. The involvement of major actors/stakeholders (host community members), experts (environmental specialists) and end users (decision makers in government and private organisations) as displayed in Figure 1.1, in selecting areas that require assistance using sustainable development criteria also adds robustness and credibility to the decision outcome.

2.5 Problems arising from Oil Activities

Petroleum exploration and production activities in southern Nigeria dates back to the early 1900s when it was first discovered. In 1958, Shell commenced commercially, exploring for oil in Nigeria. Subsequently other oil companies (Elf, Agip, Chevron, Mobil and Texaco) joined in the quest for oil. There are presently 606 oil fields in the Niger Delta, of which 360 are on-shore and 246 offshore (Egberongbe et al., 2006). Nigeria is the largest oil producer in Africa and the eleventh largest in the world. Oil and Gas Journal (2006), estimates Nigeria's proven oil reserved at 36 billion barrels and contains 182 trillion cubic feet (Tcf) of proven natural gas reserves mainly from onshore fields and the swampy areas of the Niger Delta region. Crude oil production and export from the Niger Delta earns over US$14.5 billion yearly and provides over 90% of the country's foreign income earnings, contributing over 70% of the Federal annual budget (Chokor, 2004).

If the oil industry is considered in view of its huge contribution to foreign exchange earning, it has achieved a remarkable success. On the other hand, the oil exploration and production activities in the last four decades like many other mining and chemical industries generate large amounts of gaseous, liquid and solid hazardous wastes that impact on the environment, leading to wide spread environmental pollution. These result from accidental and intentional incidents by oil companies and saboteurs where oil spills can have severe and long-term biological, economic, political, cultural, and social impacts (Roberts and Crawford, 2004). According to Fabiyi (2002), crude oil spill disasters are due to very many factors such as oil well blow–outs, burst and leaking pipelines or flow stations, overpressure failure and overflow of process equipment components, hose failure, failures along pump discharge manifolds, sabotage to well heads and flow lines. A summary of potential environmental impact of oil activities is presented in Table 2.2.

Table 2.2: **Potential Environmental Impact of Oil Activities (Orubu et al., 2004)**

Oil Activities	Potential Environmental Impacts
Exploration	Degradation of forest and biodiversity loss by seismic activities Destruction of agricultural land and human settlements along seismic lines Generation of noise and vibration and wastes from detonation of seismic explosives
Development	Accumulation of toxic materials from drilling materials, oil pollution of the sea, beaches or land Destruction of breeding and spawning grounds for some marine organisms. Alteration of the taste of fishes, pollution of underground water
Production and processing	Water pollution from long-term cumulative effects of produced water (with high salinity) Water and land pollution from sanitary wastes, used lubrication oil, solid waste. Air pollution from gas and oil processing and flaring production of heat. Kills vegetation around the heat area and suppress the growth and flowering of some plants diminish and reduce agricultural production destruction of mangrove swamps and salt march.
Terminal locations	Water pollution from ballast and tank washing. Deck drainage and spillage during loading operations with all its accompanying effects on the fauna and flora destruction of seabed by dredging.
Storage depots	Land pollution from effluent water and solid waste of chemical cans and rums Air pollution from storage tanks destruction of farmland for the establishment of the storage depots Water pollution from the gaseous fumes during loading.
Transportation	Destruction of seabed by dredging for pipeline installation sedimentation along pipeline routes. Water pollution from consequences of leaks from fracturing or breaking of pipe, caused by metal figure, trawlers and dredged, of seafloor failures or sabotage. Oil spill and air pollution by transport tankers. Destruction of environmentally sensitive area e.g. lowland where estuaries wet land dune exist.
Refining	Water pollution from effluents, which contain wide range of organic and inorganic pollutants such as phenols, hydrogen sulphide, ammonia, oil and greases, phosphates, cyanide and toxic metals.
Construction and dredging	Release of foam, oil, grease, scum, litter or other objectionable matter during construction Increased turbidity in water bodies Leakage of materials from barges

Fifty percent (50%) of oil spills is due to corrosion, twenty–eight percent (28%) to sabotage and twenty-one percent (21%) to oil production operations (Nwilo and Badejo, 2006). One percent (1%) of the oil spills is due to engineering drills, inability to effectively control oil wells, failure of machines, inadequate care in loading and unloading oil vessels (Nwilo and Badejo, 2006).

Between 1976 and 1998 a total of 5724 incidents resulted in the spill of approximately 2.6 million barrels of oil into the environmental media (Nwilo and Badejo, 2001). Figure 2.4 shows the data on the number of spill incidents recorded in Nigeria from 1976 to 2005. It can be observed from the figure that the highest number of spills was recorded in the late 1970s while the largest quantities are post 2000. During the period between 1978 and 1982, a number of these spills were attributed to corrosion of ageing facilities (Shell Petroleum Development Company, 1995), and relative disregard for good oil field practices (Ndifon, 1998). As mentioned earlier, oil spills are partly caused by sabotage and this has continued to be a significant challenge and cause for concern to oil companies and the Federal Government of Nigeria.

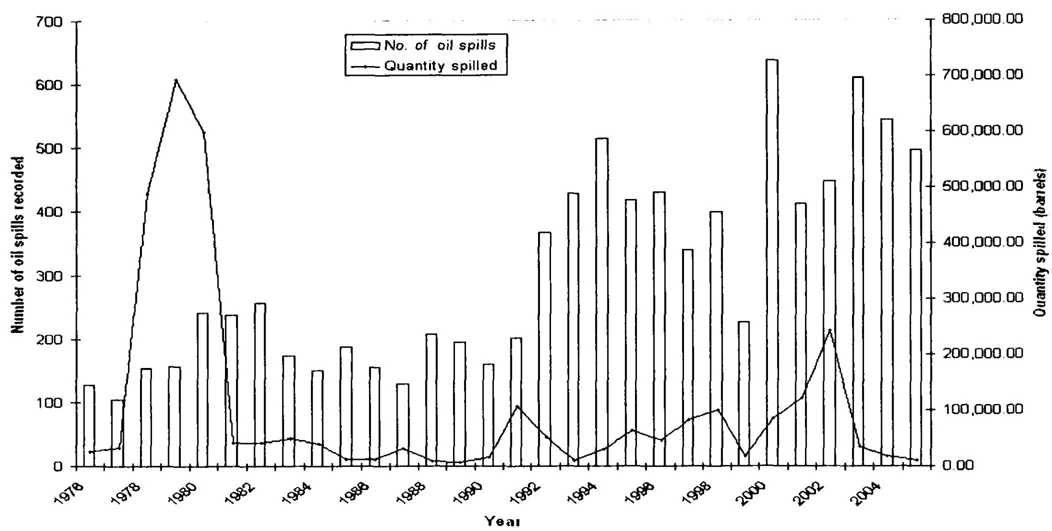


Figure 2.4: Oil Spill Rate and Volume Spilled 1976 - 2005 (Egberongbe et al., 2006)

The problem of environmental degradation and how it has hindered sustainable development and led to the impoverishment of the people of the region has been acknowledged by all and sundry e.g. (Aluko, 2004, Anyakora and Coker, 2007, Aprioku, 2003, Bloemink, 2000, Brume, 2000, Egberongbe et al., 2006, Nwilo and Badejo, 2006, Obiajunwa et al., 2002, Owabukeruyele, 2000). Oil pollution is perhaps one of the worst environmental degradation associated with the oil industry. Some of the more obvious environmental impacts of the petroleum industry include the effects of gas flaring, effects of oil spillage on flora and fauna and effects of explosions of oil pipelines (Obiajunwa et al., 2002). Some of the obvious harmful effects of oil pollution include contamination of local aquifers, surface water bodies, inhibition to vegetation growth, reduction in biodiversity and health risks to humans and animals (Adeyemi, 2004, Fabiyi, 2002, Kwarteng, 1998, Luiselli and Akanni, 2003, Osuji and Nwoye, 2007).

2.6 Summary

The chapter has highlighted the general characteristics of the study area in terms of the physical and social setting. It has revealed that despite the environmental policies and laws that were created by the government to protect the environment from degradation, much of the efforts have been futile. This could probably be due the introduction of methods that are used in developed countries without adequately adapting to the needs of the region. It has also been argued that EIA Act does not encourage the participation of people whose lives are likely to be affected by a project; rather, it encourages the collection and documentation of technical information, which is confusing and unintelligible to a majority of people. All too often, the provisions enshrined in the law are not enforced: multinational corporations seem able to evade them (Aluko, 2004). Other problems include weak enforcement of the laws and lack of technical expertise on the side of executors.

Government institutional and infrastructural effects as reviewed by this study revealed inadequacy addressing developmental challenges arising from the prolonged absence of laws and policies to guide oil activities. One of the ways of addressing the problem is the integration of indicators for sustainable development indicators and stakeholder participation. The Federal Government's infrastructural efforts to address underdevelopment have been plagued with the problems of funding.

Consequently this research proposes a framework intended at providing decision makers (end users) who may be in government or private sectors, with a set of evaluation criteria for comparing and prioritising polluted areas, for the implementation of cost-effective mitigation measures. A review of available literature reveals the absence of a suitable methodology that allows the prioritisation of contaminated areas for development in the Niger Delta region. The problem in the region has been compounded by scarcity of sound scientific data coupled with the lack of funds and the political nature of environmental issues.

This therefore raises the need to review the concepts and tools that are required in providing planners and/or decision-makers with a systematic framework to aid environmental decisions outcomes in relation to oil production and transport activities.

Chapter 3 : Literature Review - Part II (Sustainable Development and Environmental Decision Making)

3.1 Introduction

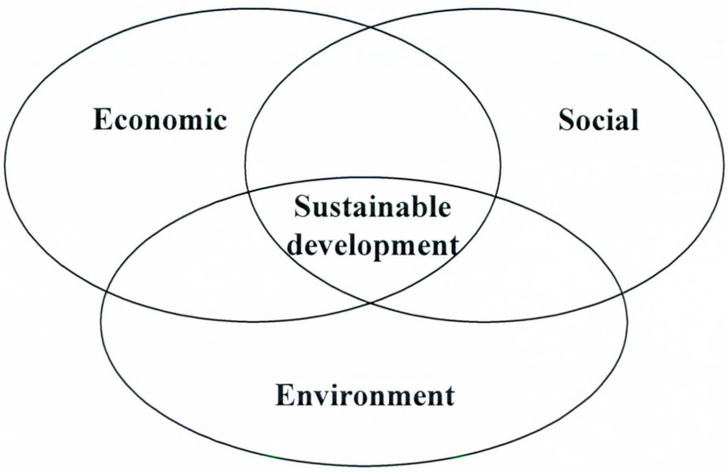
Indicators of sustainable development are essential for monitoring negative trends which can be addressed before they become a problem. Indicators can generate discussion among people with different backgrounds and viewpoints, and, in the process, help create a shared vision of what environmental management practices should be. Using an integrated sustainability approach to environmental decision making, indicators can point the way to a better future. The complexity of the decision making process introduces the utilization of a number of concepts and tools. These are discussed in details in this chapter.

3.2 Sustainable Development

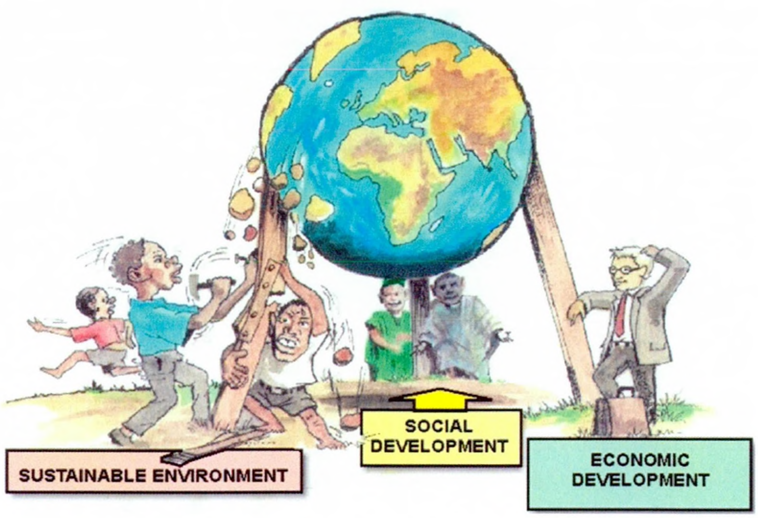
For more than a decade, sustainability has become a cogent paradigm for management of natural resources (Jakeman et al., 2006). The Scottish Executive Environmental Group (2002), describes sustainable development as combining economic progress with social and economic justice. Sustainability is related to the quality of life in a society or community. Although the definition of sustainable development remains elusive, it is possible to evaluate development proposals in terms of which options may be *more* or *less* sustainable (Gilmour and Blackwood, 2006). Despite its elusiveness, sustainable development has been defined in several ways, but the most frequently used definition is that stated in the Brundtland report (World Commission on Environment and Development, 1987).

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

The 1992 Earth Summit in Rio de Janeiro recognized the important role that indicators of sustainable development play in decision making (Giupponi et al., 2006). Such recognition was articulated in Chapter 40 of Agenda 21 which called on governments at all levels, as well as international, and non-government organizations, to develop and identify Indicators of Sustainable Development (ISDs) that can provide a solid basis for decision making at all levels. With the worldwide attention focussed on sustainable development, it becomes necessary to incorporate environmental issues with social and economic aspects as presented in Figures 3.1a and b.



(a)



(b)

Figure 3.1: Components of Sustainable Development (a) as applied in this study (b) the frustrations of the actual situation (Ogbe, 2006)

The global strategy for sustainable development (Office of Science and Technology, 1999) has the following key objectives

- Social progress which recognises the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

During the first two decades that followed, nations paid lip service to the concept of sustainable development with industrialized countries separating technological development and economic activities from the inherent ecological consequences of unplanned economic growth (Ogbe, 2006). Both the industrialised nations and developing countries have come to accept that sustainable development involves creating and maintaining our options for prosperous social and economic development and that a close relationship exist between resilience, diversity and sustainability of social-ecological systems. There is now increasing support for policies that strengthen the perception of humanity and nature as interdependent and interacting and stimulate development that enhances resilience in social-ecological systems, recognising the existence of ecological threshold, uncertainty and surprise (Folke *et al.,* 2002 in (Ogbe, 2006)).

3.2.1 Sustainable development in the United Kingdom

In response to the sustainable development aims agreed at the 1992 summit, the UK government, Scottish Executive, Welsh Assembly Government and Northern Ireland Administration agreed upon a set of principles that provide a basis for sustainable development in the UK. The five principles include:

- Living within environmental limits
- Ensuring a strong, healthy and just society
- Achieving a sustainable economy
- Using sound science responsibly
- Promoting good governance

In 1999 the UK government produced a document in relation to sustainable development titled 'A better quality of life: a strategy for sustainable development'(Office of Science and Technology, 1999). In 2005, The UK Government launched a new strategy for sustainable development titled 'Securing the future' which takes into account new policies since 1999 (HM Government, 2005).

According to Pollard et al. (2004), the UK has applied the sustainable development agenda to soil quality focussing on historic land contamination and the wider aspects of soil quality, including: (i) bringing land back into early beneficial use; (ii) reducing pressure on greenfield sites and the pollution of groundwater, thus conserving agricultural land and natural habitats; (iii) adopting a suitable-for-use approach towards land remediation; (iv) providing an efficient use of national resources to tackle issues of highest risk at priority sites; (v) prioritising remedial action so as to address the worst risks first in relation to the use of the land concerned; (vi) applying sustainable remediation technologies that conserve land and resources; (vii) developing and maintaining new partnerships and fora among key stakeholders with agreements on a common research and practice agenda; (viii) considering point and diffuse sources of soil pollution over the long term; (ix) developing monitoring systems that allow early detection of adverse soil, water and ecosystems changes; and (x) distributing impacts from land contamination on communities. They stated further that, in the UK, these issues are being addressed through a combination of policy, regulatory, voluntary and technological responses, supported in turn by the application of decision tools at the strategic and operational level.

3.2.2 Sustainable development practices in Scotland

In Scotland Sustainable development practices are guided by "the Scottish Environmental Protection Act and Sustainable Development" that was issued by the Scottish Office in November 1996 (The Scottish Environment Protection Agency

(SEPA) and Sustainable Development, 2005). The guidance ensures that sustainable development is embedded fully in Scottish Environment Protection Agency (SEPA) day-to-day activities and performance management systems. The Scottish Executive Environment Group (2003) in 2001 launched a consultation for the selection of indicators that could best measure progress towards sustainable development. Indicators were selected on their ability of being able to;

- reflect Scottish circumstances and, in particular, the distinctive Scottish priorities of resource use, energy and travel
- be compared with other indicator systems as used in other parts of the United Kingdom, Europe and at world level. For example, our matrix of indicators can be compared to the UK headline indicators
- be applied practically at a local level

A recent review by Scottish Executive Social Research (2006) provides an overview of recent and contemporary academic and 'expert' literature and prevailing debates surrounding sustainable development for a number of selected areas of policy delivery, and relates these to the principles and priorities for sustainable development in Scotland. The topics covered in the review were food, sustainable procurement, sustainable consumption, green jobs and business enterprise, the built environment, environmental protection, education for sustainable development and environmental justice.

A critical evaluation of the review material allowed the identification of three main areas, in the evidence or in policy, in which challenges and past deficiencies in the delivery of sustainable development were apparent, whether at one or more of the different national and international levels addressed in the review (Scottish Executive Social Research, 2006).

3.2.3 Application of sustainable development issues in Nigeria

Nigeria, as in many African countries, the management and conservation of the environment and natural resources was largely a community responsibility. The survival of the community depended on extensive and very intimate knowledge and sustainable use of land, forests, and wildlife resources (UNEP, 2000 in (Ogbe, 2006)). During the colonial period, the European colonial powers imported and imposed new laws and regulation which undermined and replaced the traditional community-based approach to conservation and sustainable use of natural resources (Ogbe, 2006). This paradigm shift also frosted a development pattern focused mainly on economic growth, with the export of key commodities and natural resources given priority over subsistence agriculture and internal food security. This strategic mistake created many problems for African countries, including unrealistic dependence on commodity process in world trade system dominated by the major industrialised countries and the inherent vulnerability to fluctuations in the prices of unprocessed natural resources (Ogbe, 2006).

By late 1980s, most developing countries with Nigeria being no exception were confronted by rapidly growing populations, increasing urbanisation and industrialization including oil exploration (Ogbe, 2006), exacerbating the twin problems of between poverty alleviation and environmental degradation. This presupposes that these countries have environmental strategies and commitment to effective environmental stewardship. Priority constraints to implementing effective programmes to address issues related to sustainable development as noted by Ajayi and Ikporukpo (2005), include lack of public enlightenment/ awareness on the issues of environmental problems and the mitigating measures. Other problems include insufficient funds, weak database, lack of institutional capacity and inadequate enforcement of relevant laws, standards and regulations.

To redress the problem, the National focus point for sustainable development in Nigeria became the Federal Ministry of Environment (see section 2.3.3). Its key function with regards to sustainable development was the implementation of Nigeria's National Agenda 21, which addresses the environmental implication of long term economic development programmes. Sustainable Development issues in Nigeria received a boost from the establishment of the Vision 2010 Committee in

1996. This was a body charged with the mandate of developing a blueprint of measures to ensure the realization of the country's potential as a self-sufficient country by the year 2010 (Ajayi and Ikporukpo, 2005). In addition, the country had a national Agenda 21 document to address the environmental implication of this development programme.

The major initiative of the present Federal Government of Nigeria (FGN) is a seven point agenda (Oker, 2008) which incorporates some aspects of the United Nations Millennium Development Goals (MDGs) agenda. The proposed framework will thus establish a paradigm for advancing the protection of the ecosystem and its inhabitants from further environmental degradation by utilizing a combination of the Federal Government of Nigeria seven point agenda (FGNSPA) and MDGs.

The decision support framework proposed in this research is expected to incorporate the interdependent and mutually reinforcing pillars of sustainable development – economic development, social development and environmental protection as displayed in Figure 1.4, in addressing EIA for post developmental projects and activities.

3.3 Environmental Indicators for Sustainable Development

It is well recognized that indicators are required to capture trends in ways that policy makers and others can grasp immediately (Gabrielsen and Bosch, 2003, Klasen, 2008, OECD, 2003, Scottish Executive Environment Group, 2003, Smeets and Weterings, 1999, Walker, 2001). When faced with the negative consequences of environmental degradation, it becomes necessary to collect information on the state of the environment and to translate them into an intelligible format that will inform decision makers; indicators can serve this purpose (UNEP, 2002). Combining relevant indicators into a composite index reveals much more than just using individual indicators, therefore it becomes necessary to structure a set of indicators using analytical frameworks (Giupponi *el al*, 2006).

Oil and gas exploration and production operations have the potential for a variety of impacts on the environment. These impacts depend upon the stage of the process, the size and complexity of the project, the nature and sensitivity of the surrounding environment and the effectiveness of planning, pollution prevention, mitigation and control techniques (UNEP, 1997). The issue of ecosystem fragility or vulnerability to exogenous and endogenous stress factors has been the subject of long and intense debate (Villa and McLeod, 2002). This debate has deeply influenced the development of modern ecology and produced enormous insight into ecosystem structure and function. However, the debate has not led to agreement on the definition of these properties and has not produced general and practical conceptual models to calculate corresponding indicators. Instead, a synthesis of the current knowledge could lead us to conclude that, due to the complexity, nonlinearity, and multiplicity of temporal and spatial scales typical of natural systems, a sufficiently general conceptual model of this kind will probably never be developed (Villa and McLeod, 2002).

The need for answers in short time frames has led scientists to attempt surrogate measures calculated on the basis of available or easily measurable indicators, which have been and are being developed to serve as a basis for critical decision-making, often involving some of the most important ecosystems on Earth. The World Bank now includes environmental indicators on the list of what constitutes sustainable development (Niger Delta Environmental Survey, 1997, Segnestam, 2002). There are many definitions of environmental indicators. One formal definition describes an environmental indicator as any component of the environment that qualitatively estimates the condition of ecological resources, the magnitude of stress, the exposure of biological components to stress, or the amount of change in condition (Klemas, 2001, UNEP, 2006). With the global trend towards sustainable development, there is the need to integrate environmental issues with social and economic aspects (Adomokai and Sheate, 2004). The three aspects are intimately related and need to be addressed together to improve the quality of life in the Niger

Delta region. A good knowledge of the state of the environment requires the acquisition of data relating to the physical, chemical, biological and socio-economic data. The collected data are then translated to environmental indicators.

Gabrielsen and Bosch (2003) defined

"an indicator as an observed value representative of a phenomenon of study. In general, indicators quantify information by aggregating different and multiple data. The resulting information is therefore synthesised. In short, indicators simplify information that can help to reveal complex phenomena."

Environmental indicators have three basic functions; simplification, quantification and communication (Environment Agency, 2006, Gabrielsen and Bosch, 2003, OECD, 2003, Scottish Executive Environment Group, 2003, The Scottish Environment Protection Agency (SEPA) and Sustainable Development, 2005). Ideally they meet the following criteria:

- Scientifically sound
- Easily understood
- Shows trends over time
- Sensitive to the change that they are intended to measure
- Measurable and capable of being updated regularly

In selecting indicators it is desirable to identify those that reflect the response of other indicators. In relation to policy-making, environmental indicators are used for major purposes such as (Gabrielsen and Bosch, 2003):

- To supply information on environmental problems, to enable policy-makers to value their seriousness;
- To support policy development and priority setting, by identifying key factors that cause pressure on the environment;
- To monitor the effects of policy responses.

In addition, environmental indicators may be used as a powerful tool to raise public awareness on environmental issues (Gabrielsen and Bosch, 2003, OECD, 2003, Scottish Executive Environment Group, 2003, The Scottish Environment Protection Agency (SEPA) and Sustainable Development, 2005). They also measure progress in a tightly interconnected manner and not in traditional ways where each indicator is entirely independent of the other parts.

3.3.1 A conceptual framework using DPSIR approach

At present, a variety of environmental indicators are in use (Gabrielsen and Bosch, 2003). These indicators reflect trends in the environment and monitor the progress made in realising environmental policy targets. As such, environmental indicators have become indispensable to policy-makers. (Smeets and Weterings, 1999). Estimating the effects of a policy measure requires the identification of the causal links between the implementation of the measure, and its ultimate impact on human activities and the environment (Fassio et al., 2005). Figure 3.2 provides a conceptual framework for examining those links, that may be found in the Driving forces-Pressure-State-Impact-Response (DPSIR) approach proposed by the European Environmental Agency (EEA) for describing environmental pathways. Fassio et al.(2005) further noted that in a policy making context, this approach can support the policy maker in conceptualising and structuring the decision about alternative possible measures, according to those cause–effect relationships.

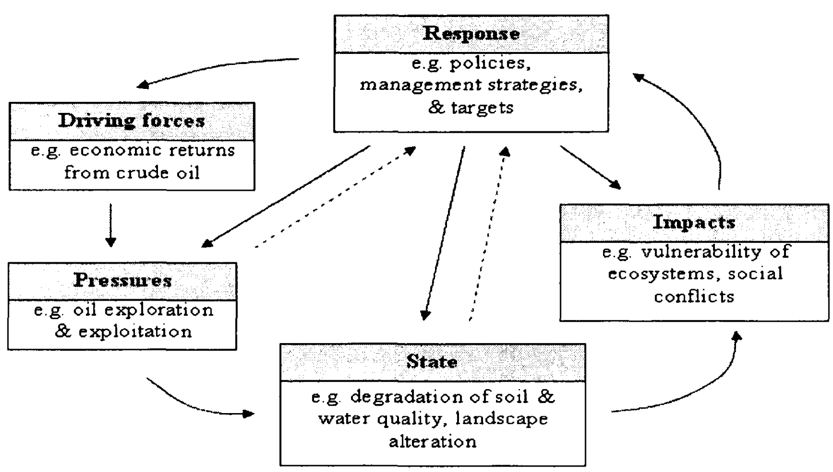


Figure 3.2: **DPSIR framework (modified after Smeets and Weterings 1999)**

Two features of the DPSIR model have contributed to its wide use. First, it structures the indicators in relation to political objectives related to controlling the environmental problem addressed, and second, it focuses on presumed causal relationships, which appeal to policy actors. The DPSIR framework is useful in describing the relationships between the origins and consequences of environmental problems (OECD, 2003).

According to this systems analysis view, social and economic developments exert Pressure on the environment and, as a consequence, the State of the environment changes, such as the provision of adequate conditions for health, resources availability and biodiversity. Finally, this leads to Impacts on human health, ecosystems and materials that may elicit a societal Response that feeds back on the Driving forces, or on the state or impacts directly, through adaptation or curative action. Most sets of indicators presently used by nations and international bodies are based on the DPSIR-framework or a subset of it (EEA, 1999). They include

(1) Indicators for driving forces describe the social, demographic and economic developments in societies and the corresponding changes in life styles, overall levels of consumption and production patterns.
(2) Pressure indicators describe developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land.
(3) State indicators give a description of the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric CO^2 - concentrations) in a certain area
(4) Impact indicators are used to describe these impacts. Impacts occur in a certain sequence: air pollution may cause global warming (primary effect), which may in turn cause an increase in temperature (secondary effect), which may provoke a rise of sea level (tertiary impact), which could result in the loss of biodiversity.

(5) Response indicators refer to responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment.

Although the DPSIR framework was applied in this research, modifications were made in the selection measurable indicators. Additionally, the relationship between the indicators also deferred from the generic framework as shown in the broken arrows in Figure 3.1.

3.4 Environmental Decision Making (EDM)

The importance of making environmental decisions have been already been discussed (see section 1.4). In order to develop model-based decision-support framework for environmental management and policy analysis, one or more of the steps in the environmental decision-making process need to be considered. The main factors that have an impact on whether environmental problems are addressed, and how this is done, as defined by (Giupponi, 2007) is shown in Figure 3.3.

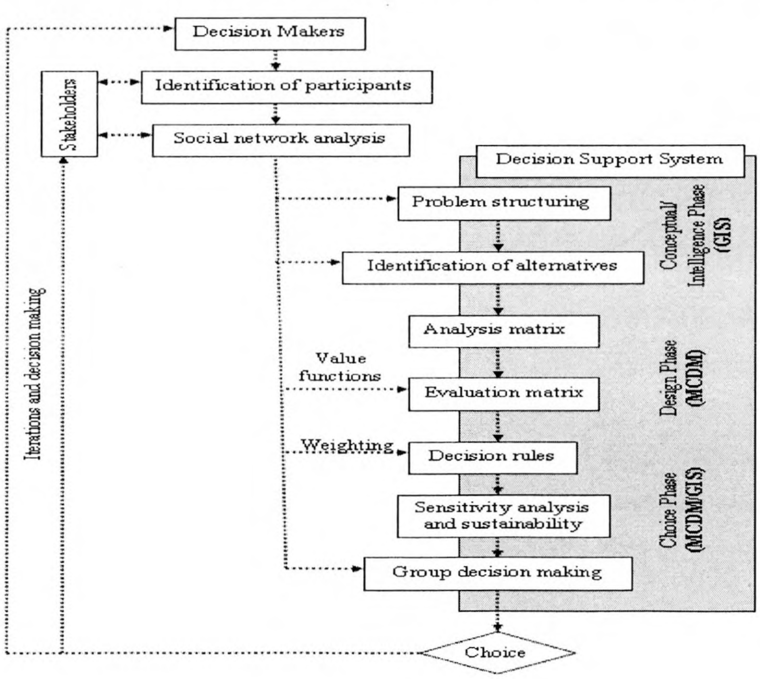


Figure 3.3: Flowchart of Environmental Decision Making (Giupponi 2007)

In this framework the planning and decision-making process is an iterative and recursive activity going through the phases of understanding the problem or opportunity (intelligence), finding or developing alternative solutions (design solutions) and arriving at a preferred solution. The intelligence phase amounts to building a concept or model (qualitative or quantitative) of the processes at play, where one first describes the phenomenon, tries to understand its behaviour, assesses the current situation, and derives objectives, which are to guide further steps. The design phase requires different models (again either qualitative or quantitative) to generate alternative solutions. Finally, a preferred alternative has to be agreed upon, through some assessment of factual impacts, evaluation (i.e. judgment) of these impacts and communication explaining the rationale of the decisions (Sharifi and Rodriguez, 2002).

Recently, however, the effort to integrate new tools to deal with more complex systems has led to the development of the so-called Environmental Decision Support Systems (EDSS) (Poch et al., 2002). The formulation of the problem in terms of the DPSIR framework has been implemented into EDSS such as MULINO (Fassio et al., 2005) following the three phases of the decision process as displayed in Figure 3.4.

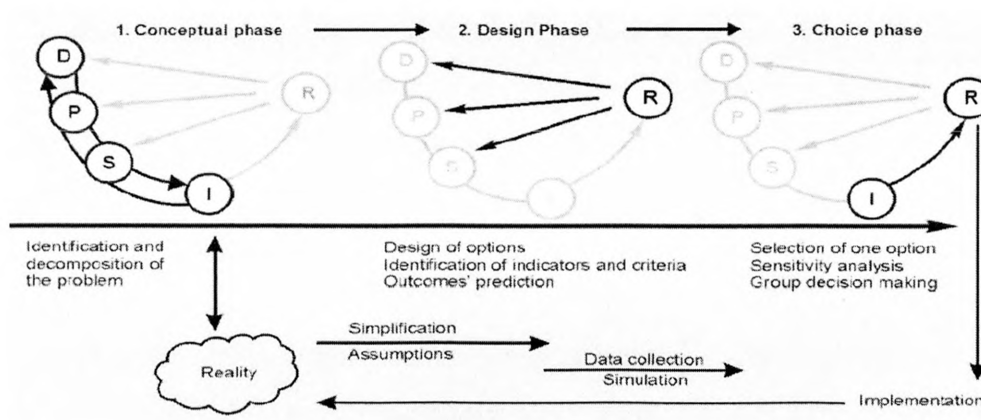


Figure 3.4: Conceptual framework of EDSS, in accordance with the DPSIR approach (Fassio et al., 2005)

The methods, criteria and values that are used by groups and individuals to help them make decisions can have a significant influence on the decision and how others view the decision process and outcomes (Meacham, 2004). In making a decision, it is useful to establish a set of criteria against which each alternative will be judged. However, it is not always easy to find ways by which to weigh the relative importance of the various decision criteria, as some alternatives are difficult to quantify numerically. As environmental decision making is very context dependent and often not understood in its complexity, qualitative/quantitative methods is applied (Maier and Ascough II, 2006).

Tonn *et al*, (2000), identified four interrelated components that help shape environmental decision making; goals and values, perceptions and beliefs, collective knowledge and institutional structure. Environmental decision making, occurs whenever a decision must be made that affects the present or future quality of the environment. A decision can be seen as a response to actual or potential problems; thus decisions are integral part to the problem solution (NCEDR, 1996). Most problems concerning the environment require a wide range of knowledge, as such no academic discipline has a monopoly on environmental decision making, rather the examination of environmental decisions require an integrated effort from many disciplines. According to Meacham (2004), the decision-making process has several distinct but interrelated steps beginning with identifying the problem and ending with implementation of the solution. An ideal decision process should have the following steps;

- Problem identification and goal (objective) definition
- Identify and evaluate criteria alternatives
- Apply decision tool
- Make decision
- Implement decision
- Evaluate decision

This general outline can be applied to different types of decisions. However the details and complexity of each stage obviously vary greatly between different applications. According to NCEDR, (1996) and Chicheli, (1991), aspects of environmental decisions which make it more difficult than many other kinds of decisions, include

1. new stakeholders are involved compared to traditional societal problems (especially laypeople and affected people)
2. the problems do not fit administrative boundaries
3. the distribution of costs and benefits is unclear
4. the valuation of environmental assets is very difficult
5. involve greater uncertainty

3.4.1 Multi-criteria decision making (MCDM)

Multi criteria decision-making (MCDM), can been incorporated into EDM as shown in Figure 3.3 in order to address the deficiencies mentioned in section 3.4. MCDM, is by now a well recognized paradigm in environmental studies and is one of such decision tools that enable rigorous selection of the most preferred choice in a context where several criteria apply simultaneously (Mendoza and Prabhu, 2000). MCDM has desirable features that make it suitable for solving complex problems that are characterized by any mixture of quantitative and qualitative objectives given a set of criteria/indicators. This process, in which several criteria are evaluated in order to meet the specific objective, is also characterized by some level of assumed risk that strongly influences the final decision outcome (Ghribi, 2004). To minimise the risk and reduce the errors of the objectivity of the decision, it is better to have a group of decision-makers rather than a single decision maker. The group could be composed of experts with different backgrounds and local communities (refer to section 4.4.1 for further discussion). The advantages of MCDM include:

- Capability to accommodate multiple criteria in the analysis.
- It is participative allowing direct involvement of multiple stakeholders (actors) such as proponent (initiator, developer), competent authority

(decision maker, authoriser), advisor (regulators), experts (professionals), and the public (interest groups).

- Analysis need not be data intensive. In fact, the procedure can be used with minimal amount of information. In some cases, expert opinions may be used in the absence of adequate data.
- MCDM can work with mixed data. It allows for the incorporation of both qualitative and quantitative information.
- Analysis is transparent to participants depending on the MCDM technique applied.

MCDM can further be divided into multi objective decision-making (MODM) and multi attribute decision-making (MADM) (Pohekar and Ramachandran, 2004, Vàzquez and Rosato, 2006). In the values of MODM decision variables to be determined are continuous with infinite or large number of choices or objectives while MADM are discrete usually limited, number of alternatives (Zanakis et al., 1998). Table 3.1 presents the basic differences between MADM and MODM.

Table 3.1: **Comparison of MADM and MODM approaches (Vàzquez and Rosato, 2006)**

	MADM	MODM
Criteria	Attributes	Objectives
Objectives	Implicit	Explicit
Attributes	Explicit	Implicit
Constraints	Inactive	Active
Alternative	Finite, Discrete	Infinite, Continuous
Use	Selection, Evaluation	Design

The major reason for applying MADM technique in this study is due to the fact that there is just one objective which is expected to be achieved with a number of attributes. Also the criteria selected were finite and discrete.

3.4.2 Problem definition

An important preliminary step in the process for the decision maker or the individual with the authority to implement an action with respect to environmental planning and management is to define the desired goal, objective, or purpose for the action being sought (Strager, 2002b). Problem definition is in the conceptual phase of decision making it encompasses exploring available information to identifying the problem. Defining desired goal, objective or purpose of the need to be addressed is established in this phase. Within this first step the objective of the decision making process is also clearly defined along with an identification of the key players or participants; i.e., decision makers as well as people who may be affected by the decision.

3.4.2.1 Identification and selection of participants

The multi-criteria decision support framework requires the engagement of three main types of participants as presented Figure 3.5. As mentioned previously in section 1.4, stakeholder involvement is of essence in EIA, especially in conflict management. The first tier includes stakeholders who provide information for use in DSS. A stakeholder can be defined as a person or group who can affect or is affected by the outcomes of the decision at hand (Proctor and Qureshi, 2005). An ever greater emphasis is given in recent times to the involvement of stakeholders, in the development and implementation of DSS tools (Matthies et al., 2007).

The second tier represents those participants that provide the concepts and expert knowledge required. The third tier represents the end users of the framework.

Figure 3.5: Stakeholder participation and information flow in Environmental Decision Making

3.4.2.2 Definition of appropriate evaluation criteria

Defining appropriate evaluation criteria is an essential step required to achieve the required objective in a decision making process. This stage involves specifying a comprehensive set of alternatives that reflects all concerns relevant to the decision problem and measures for achieving the objective. Because the evaluation criteria are sometimes related to geographical entities and the relationships between them, they can be represented in the form of maps which are referred as attribute maps. GIS data handling and analyzing capabilities are used to generate inputs to spatial decision making analysis (Malczewski, 1999).

3.4.3 Multi-criteria analysis (MCA)

The literature covering methods or aids in the process of decision-making is extensive and, covers many different types of applications in many different disciplines (Ascough et al., 2002, Atkinson et al., 2005, Balasubramaniam et al., 2007, Bell et al., 2003, Boerboom et al., 2004, Cavalcante et al., 2005, Claassen, 2007, De la Rosa et al., 2004, Ellis et al., 2004, Fassio et al., 2005, Feoli, 2004, Geneletti et al., 2007, Giupponi, 2007, Kontos et al., 2005, Linkov et al., 2006, Matthies et al., 2007, Morais and Almeida, 2006, Turon et al., 2007, Vàzquez and Rosato, 2006, Zarkesh, 2005). This may be one reason why there appears to be little consensus as to the correct naming of the particular class of decision tools used. For example, the terms Multi-criteria Evaluation, Multi-criteria Analysis and Multi-attribute decision-making are terms which refer to the same methodology (Yoon and Hwang, 1995).

The terminology used in this study is in consonance with those of Proctor and Qureshi (2005), where the term 'alternative' is used and is synonymous with terms such as 'option', 'plan', 'policy', 'action' and 'candidate' used in other studies. 'Alternatives' are those outcomes, policy options or resource use scenarios that are to be decided between. Ultimately the chosen alternative will be that one that best satisfies some overall objective or goal.

According to Atkinson et al.(2005), an objective is understood here to imply a perspective, philosophy, or motive that guides the construction of a specific multi-criteria decision rule. The term 'criteria' refer to those aspects of each alternative that need to be assessed as to how well each of them meets the desired objective. In some studies though it is synonymous with the terms 'goals' and 'attributes' found in other studies (Yoon and Hwang, 1995). Within the context of this research, MCA using the terms objective, criteria, alternative path was found to be appropriate in structuring and evaluating problems in decision making process.

3.4.3.1 Assignment of criterion scores and weights

Scores can be assessed in many ways including simulation models, laboratory tests, direct measurement and expert judgement (Giupponi et al., 2006). Criterion scores can be made using two distinct measurement scales, quantitative and qualitative. In the case of a quantitative scale, the measurement unit is known. In general, data alone offer limited insight until value and significance to the decision are applied by decision makers and stakeholders (Stahl et al., 2002). Hence it is necessary to assign a numerical score on the strength of preference scale for each option for each criterion. In the case of this study, quantitative criteria scores are based on empirical data while qualitative criteria scores were elicited from stakeholders affected by the decision outcome. Standardisation is applied to obtain comparable scales in raw data sets, to allow for comparisons among criteria.

The assignment of weights is an essential step in the decision making process. The purpose of weighting attributes, or criteria is to express the importance of each relative to each other for use in a ranking model (Strager, 2002a). Weighting is a process of prioritising criteria that can be subjective in nature, particularly where it relies upon the judgement of participants (Balasubramaniam et al., 2007). The most popular techniques include ranking, rating, pairwise comparison, and trade-off analysis (Malczewski, 1999, Strager, 2002a). Each differs in terms of accuracy, ease of use, complexity for participants to understand, and theoretical foundation. In all of the techniques presented, a common characteristic is the normalization of the weights (sum to one) so they can be combined.

Depending the quality of data and the method used for the assignment of scores and weights range from the simplest method - ranking method to more complex methods such as pairwise comparison. In the ranking method criteria are ranked from most important to least importance. The rating method requires the decision maker to estimate weights on the basis of a predetermined scale.

The Analytic Hierarchy Process (AHP) developed by Saaty (1980) provides a hierarchic framework for pairwise comparison of multi-criteria problems. AHP uses the definitions of relative importance to evaluate the weights received by individual decision criterion and the score received by each option for a given criterion. It is one of the most widely used multiple criteria decision-making tools with several outstanding works published based on it: they include applications of AHP in different fields such as planning, selecting a best alternative, resource allocations, resolving conflict and optimization (Vaidya and Kumar, 2006). AHP has been applied in many and diverse areas of decision-support, with respect to natural resource and environmental management in Australia (Qureshi and Harrison, 2003).

The essence of Analytical Hierarchy Process (AHP) is to decompose a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy (Pohekar and Ramachandran, 2004). The procedure as outlined by Saaty (1980) rates the importance of each factor, or criterion, relative to every other factor using a 9-point reciprocal scale as provided in Figure 3.6.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very	Strongly	Moderately	Equal	Moderately	Strongly	Very	Extremely
Less Important				→				More Important

Figure 3.6: Nine point reciprocal scale developed by Saaty (1980) for assignment of weights to criteria

In pair-wise comparison, consistency within comparisons is important. Saaty (1980), states that a consistency ratio (CR) of 0.10 or less is considered acceptable. The CR value is the probability that the weights are random (Atkinson et al., 2005). CR can be estimated from Equation (3.1).

$$CR = \frac{CI}{RI} \qquad (3.1)$$

where *CI* is the Consistency Index derived from (Equation 3.2)

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (3.2)$$

where λ_{max} is the largest eigen value of the comparison matrix and n is the number of criteria. *RI* is the Radom Consistency Index which can be obtained from existing tables such as Table 3.2 that established the relationship between n and RI.

Table 3.2: Random Consistency Index (RI) for different n values

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The AHP is applicable to single or multiple decision-makers, and based on the innate human ability to make sound judgments about small problems. It also provides a means to integrate facts with subjective judgments.

AHP presumes the use of computers to handle the mathematical complexities while providing a relatively simple method for user's to express preferences for complex issues (Itami et al., 2000). Due to its theoretical soundness (where values assigned for criteria weights can be gauged by the consistency ratio), the AHP was applied in validating the criteria weights obtained for prioritising polluted sites. The application of AHP for weight assignment is described further in section 8.4.2.1

Another method is the trade-off analysis. This method makes use of trade-offs that the decision maker is willing to make between pairs of alternatives. The approach requires the decision maker to compare two alternatives (say A and B) with respect to two criteria at a time and assess which alternative is preferred. Specifically, the decision maker has to determine if alternative A is preferred to B, if alternative B is preferred to A, or no preference exists between the two alternatives. By asking for such judgments, one can deduce how much weight the decision maker must have given to the various criteria.

A critical assumption behind this method, is that the tradeoffs the decision maker is willing to make between any two criteria do not depend on the levels of the other criteria (Malczewski, 1999). It is suggested that the tradeoff procedure should only be used with objectively quantified evaluation criteria (Malczewski, 1999). It is much more difficult to use with subjective criteria as one of the assumptions of the method is that the decision maker can make minor judgments between criteria.

This research applied two methods for the assignment of scores and weights. The ranking method was used in eliciting scores from stakeholders. It was selected due to its ease of use and there was less difficulty in explaining the process to the different stakeholders. The second method chosen was the pairwise comparison. This was essentially used for the validation of results. Although the advantage of pairwise is in its theoretical foundation, it was difficult to explain the procedure to stakeholders.

One of the main advantages of using MCA in the assignment of scores and weights is the ability to integrate both quantitative and qualitative data. The major criticism of the methods outlined above is that different techniques yield different results when applied to the same problem, apparently under the same assumption and by a single decision maker (Zanakis et al., 1998). Furthermore the wide variety of available techniques, of varying complexity and possible solution, confuses potential users.

3.4.3.2 Evaluation techniques

Evaluation or aggregation techniques can be broadly classified as compensatory techniques and non-compensatory techniques. Compensatory techniques aggregate the criteria to an overall utility function; these include all methods using the weighted summation aggregation technique, MAUT and the Analytic Hierarchy Process (AHP). In these techniques, poor performance in a possibly critical criterion is compensated for by good performance in other criteria. Non-compensatory techniques include a measure of discordance; options that include poor performance against an individual criterion will be attributed poor overall performance (Hayashi 2000).

An MCA problem can be expressed in an evaluation or performance matrix where alternatives are represented by columns, criteria as rows and scores occupy cells. According to Carver (1991), the evaluation matrix (E) can thus takes the following form:

$$E = \begin{bmatrix} f_{11} & \cdots & f_{1j} \\ \vdots & & \vdots \\ f_{i1} & \cdots & f_{ij} \end{bmatrix} \qquad 3.3$$

where f_{ij} is the evaluation score, j is the set of alternatives, i is the set of criteria. Each value is expressed with respect to the ith criterion. In the basic form of MCA, the evaluation matrix may be the final product of the analysis, while in the more analytical MCA techniques, the information is the basic matrix which is usually converted into consistent numerical values. The performance matrix enables the scoring and weighting of criteria to be achieved. This section describes the different evaluation techniques available.

Weighted Summation Method (WSM)

WSM, also known as the Simple Additive weighting (SAW) and Weighted Linear Combination (WLC) is the most popular evaluation method, mainly because of its simplicity. It assumes additive aggregation of criterion values, which are normalised to make them comparable by means of value functions (Giupponi, 2007). The value accorded to an option is the sum of the value the option receives for each criterion multiplied by the weight given to that criterion. The weighting of the criteria is derived from the weighting technique chosen by the user or decision-maker. The weighted summation is one of many Multi-Attribute Utility Models ((Joerin and Musy, 2000, Joerin and Theriault, 2001, Kangas et al., 2001, Pohekar and Ramachandran, 2004, Triantaphyllou and Sánchez, 1997, Zanakis et al., 1998) and whilst other models have a stronger theoretical basis they are rarely used because they are complicated and time consuming (Winterfeldt and Edwards 1986).

Analytical Hierarchy Process (AHP)

This method represents the 'American school' of Multi-Criteria decision making (MCDM) and has already been discussed previously in details (refer to pairwise comparison in section 3.4.3.1).

Other evaluation techniques

In addition to the techniques already discussed, there is also the Multi-Attribute Utility Theory (MAUT) developed by Keeney and Raffia (1976). It is a procedure for evaluating objects wherein a set of attributes is developed that characterises the objects, and each object is evaluated on each attribute. It is based on the Bernoulli's concept that choice depends on the probabilities of various consequences of a decision and on the utility of those consequences to the individual (the decision maker) (Meacham, 2004). It takes into consideration the decision maker's preferences in the form of utility functions, which may be defined over a set of attributes (Pohekar and Ramachandran, 2004).

The outranking techniques which represent the 'European school' of Multi-Criteria Decision making (MCDM) (Kangas et al., 2001), also known as concordance methods, provide an ordinal ranking and sometimes only a partial ordering of the alternatives. This implies that they can only express which alternative is preferred but cannot indicate how much. Of the concordance approaches, ELECTRE (Elimination et choix traduisant la réalité or Elimination and choice corresponding to reality) methods, such as ELECTRE II, III, and IV, are the most widely known (Balasubramaniam et al., 2007). One option is said to outrank another if it outperforms the other on enough criteria of sufficient importance (as reflected by the sum of the criteria weights) and is not outperformed by the other option in the sense of recording a significantly inferior performance on any one criterion (DTLR, 2001). The Preference Ranking Organisation MeTHod for Enrichment Evaluation (PROMETHEE) I and II are other commonly used outranking methods. PROMETHEE I is used for partial ranking while PROMETHEE II is used for complete ranking (Macharis et al., 2004).

Finally the compromise programming defines the best solution as the one in the set of efficient solutions whose point is the least distance from an ideal point (Zeleny, 1982). It can be described as employing a normalized hierarchical distance from an ideal solution (Manoliadis, 2002).

Two compensatory techniques were applied in this research, namely the WSM and AHP. Although the WSM lacks theoretical basis, it was selected due to its simplicity. The AHP was therefore required to validate the results obtained from WSM.

3.4.4 Spatial multi-criteria decision

Spatial decision problems usually involve a large set of feasible alternatives with multiple conflicting and incommensurate evaluation criteria (Malczewski, 2006). The problem is then to identify the best (i.e. the most preferred) alternative and also determine a ranking of the alternatives when all the decision criteria are considered simultaneously (Triantaphyllou et al., 1997). Spatial multi-criteria decision (SMCD) refers to the application of MCA in spatial context where alternatives, criteria and other elements of the decision problem have an explicit spatial dimension (Chakhar and Mousseau, 2007). Problems associated with SMCD typically involve a set of geographically-defined alternatives events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Jankowski, 1995, Malczewski, 1996).

According to Giupponi et al. (2002), unlike the decision model dealing with the classic MCA problems, in spatial decision-making the options are represented as a collection of points, lines, and areal objects with associated attributes: the consequence of this is that the decision outcomes may have spatial extension. For example, there are three possibilities i.e. null, one or two dimensional spatial outcomes as shown in Figures 3.7a, b, and c respectively.

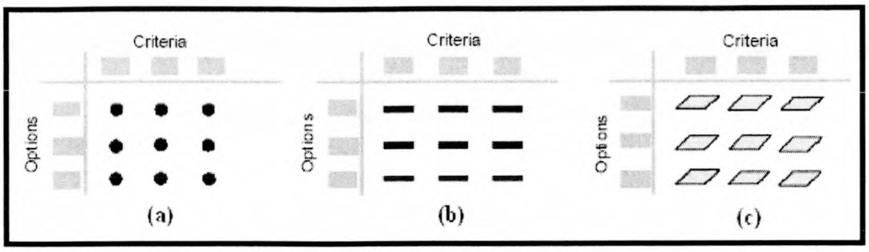


Figure 3.7: **Different dimensions of decision outcomes: spatial dimension 0 (a); 1 (b) and 2 (c) (Giupponi et al., 2002)**

The critical aspect of spatial multi-criteria analysis is that it involves evaluation of geographic units based on the criterion values and the decision maker's preferences with respect to a set of evaluation criteria (Malczewski, 1999). Spatial multi-criteria analysis is vastly different from conventional MCDM techniques due to inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, spatial multi-criteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria (Ascough et al., 2002). Ascough et al. (2002) further stated that the analysis results are dependent not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two aspects are of vital importance for spatial multi-criteria decision analysis: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives) (Carver, 1991, Jankowski, 1995).

Defining a function that aggregates also the spatial component is rather complicated, therefore the function is simplified by dividing it into two operations (i) aggregation of the spatial components, and (ii) aggregation of the criteria (Zarkesh, 2005). These two operations can be executed in different pathways as displayed in Figure 3.8.

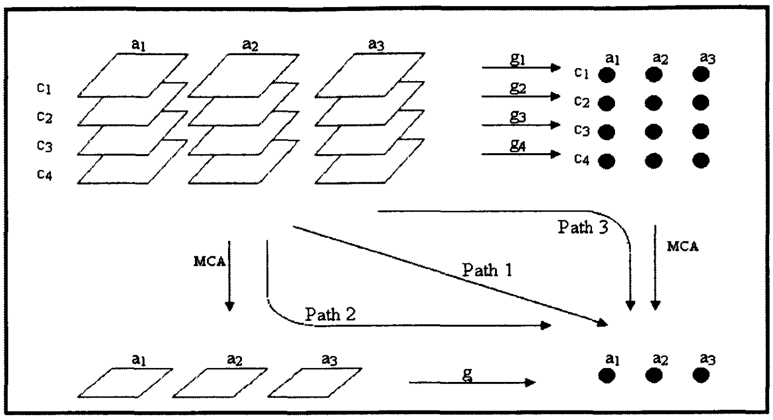


Figure 3.8: Three paths of spatial multi-criteria analysis (Jassen et al 2005)

Path 1 is by far the most common approach: the decision maker is offered all maps and it is left to the decision maker to process the information in most cases without additional support (Janssen et al., 2005). If the information presented is complex this approach can easily lead to the wrong conclusion (Uran, 2002). In the second path, the criteria represented by maps are aggregated into one map representing the overall performance of an option. In order to obtain a ranking of options, the vector of maps has to be aggregated (Giupponi et al., 2002). Path 3 starts with spatial aggregation followed by multi-criteria analysis. In many cases only the first step of paths 2 and 3 are performed (Janssen et al., 2005). Due to the difficulties involved in aggregating information obtained from maps and tables, this work used path 1 for spatial multi-criteria analysis (section 7.2.1.1).

3.4.5 Sensitivity analysis

Sensitivity analysis examines the extent of variation in predicted performance when parameters are systematically varied over a range of interest, either individually or in combination (Proctor and Qureshi, 2005). Sensitivity analysis provides further confidence in a model, and indicates priority areas for refinement if further versions of a model are to be developed.

According to Proctor and Qureshi (2005), sensitivity analysis is carried out for several reasons. The first is because of the nature of the MCE process, which inherently contains varying levels of uncertainty because of the qualitative and subjective choice of various parameters. MCE has been criticised for being and 'inexact' procedure on these grounds making it very important to test how robust the results are.

A second and very important reason is that the sensitivity analysis of the MCE procedure enables the data and the decision making problem to be explored at greater depths. This provides greater insights into the nature of the decision problem unravelling its complexities and may even provide recommendations for future analyses. A sensitivity analysis of the results may be carried out in order to take into account the uncertainty in estimating some of the figures involved. A decision-maker may be unsure of a particular weighting and may provide a range of weightings which can be analysed.

Similarly, the impacts of the various options under different criteria may fall within a statistically estimated range that can be incorporated into the analysis. Sensitivity analysis can also consider the effects of different techniques used in the weighting procedure, for example. It is very important that the sensitivity of outcomes can be tested for different values of the most crucial and contentious criteria and impacts.

For example, in a group decision-making situation, if it were found that there was a great disparity in preferences for a certain criterion then it may be enlightening to find out how the overall results change with the changes in preference levels for this criterion. If the results are not greatly affected, then the criterion can take less importance in the overall process and the decision-makers can concentrate on other criteria and trade-offs. If the results are extremely sensitive to this criterion, then closer scrutiny should be given to it by confirming values and measurements (Proctor and Qureshi, 2005). The way to overcome the subjective nature of using MCA was to engage experts in the field of environment and natural resources.

3.5 Environmental Vulnerability Assessment

Vulnerability levels and trends need to be assessed regularly to provide early warning and response measures to reduce the economic costs (Diop, 2003). Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006). Within the realm of conservation planning, Pressey et al. (1996) defined vulnerability as the likelihood or imminence of biodiversity loss to current or impending threatening processes.

Vulnerability is defined by United Nations ISDR (2002), as a set of conditions and processes resulting from physical, social, economical, and environmental factors, which increase the susceptibility of a community to the impact of hazards. Positive factors, that increase the ability of people and the society they live in, to cope effectively with hazards, that increase their resilience, or that otherwise reduce their susceptibility, are considered as capacities.

Vulnerability assessment aims at identifying and assessing criteria for ecosystem targets such as humans, water (groundwater) and vegetation (mangrove). These can be further utilized in selecting areas that are most vulnerable to pollution from oil activities. Therefore, such derived criteria will help focus efforts to sensitive environmental areas where rehabilitation can then be concentrated. The selection of evaluation criteria are determined based on relevant literature review dealing mainly with the selection of solid waste land filling sites (Carlon et al., 2008, Tixier et al., 2006). The evaluation process and spatial statistical methods using MCA and GIS is innovative for environmental vulnerability assessment.

3.5.1 Components of environmental vulnerability assessment

The idea of vulnerability developed in this research is to define it in terms of possible targets. It therefore requires identifying the major target such as humans, groundwater and vegetation (mangrove) as presented in Figure 3.9.

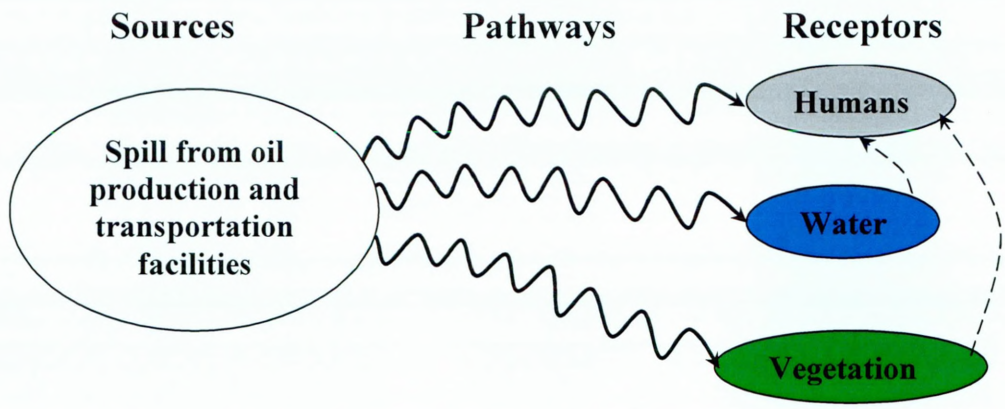


Figure 3.9: Source-pathway-receptor for vulnerability assessment (major emphasis was placed on human receptors)

3.5.1.1 Human vulnerability assessment and conflict management

The strive towards economic development often leaves developing countries, with already weak state administration, weak legal framework and inactivated civil societies exploiting for one or two natural resources, generating few spin-offs and qualified job opportunities (Torell, 1997). The causes of major crisis in some regions can often be traced to the natural resource control, environmental degradation, activities from outside the region and marginalisation of relevant stakeholders. Zeng et al. (2001) noted that there are numerous interest groups in coastal zone, each of which has its own focus on particular aspects of coastal environment. Beginning mostly in the 1990s, scholars began to recognize that conflict is associated with location (Brody et al., 2006). According to Torell (1997), when formulating policies and strategies for development of conflict regions, the following should be taken into consideration 1) Define the geographical area; 2) Collect information about physical environment, the eco-system, social structures, etc.; 3) Prepare and develop policies and strategies for resource utilization; 4) Evaluate the considered policies and strategies; 5) Include public participation in the process of strategy development; 6) Implementation and evaluation.

The degradation of Niger Delta environment and the resulting crisis has led to partial socio-economic strangulation of the Nigerian economy. Thus there is need to address the current problem in order to inform policy makers with the appropriate approach to conflict management.

Decisions relating to land use are typically complex owing to the unavoidable tradeoffs inherent in protecting or developing specific lands, and the differential impacts on various stakeholder groups (Malczewski et al., 1997). Also at community level, it is difficult to obtain comprehensive environmental and socio-economic data; consequently to augment the gap, stakeholders (community members) will be involved in the task of assessing selected criteria/indicators. In this application, stakeholders (host community members) are of most importance; therefore the framework used in the study incorporates the views and responses from stakeholders.

One approach to incorporating preferences of interest groups into formal decision analysis procedures is to use multi-criteria decision analysis (MCDA). Multi-criteria decision analysis has been widely applied to mapping risks of agricultural pollution (Giupponi et al., 1999), to land use planning and management (Malczewski et al., 1997, Joerin and Musy, 2000), environmental decision making (Kiker et al., 2005), flood vulnerability assessment (Yalcın and Akyurek, 2004), potential degree of conflict associated with oil and gas production activities (Brody et al., 2006).

The terms vulnerability and adaptive capacity, are relevant in the biophysical realm as well as in the social realm (Gallopin, 2006). Vulnerability in the human sciences is typically identified in terms of three elements (Research and Assessment Systems for Sustainability Program, 2001):

- system exposure to crises, stresses, and shocks;
- inadequate system capacities to cope; and
- severe consequences and attendant risks of slow (or poor) system recovery.

Two models have informed vulnerability analysis: the risk-hazard (RH) and pressure-and-release (PAR) models (Turner et al., 2003). The absence of the sustainability theme in these models refocuses vulnerability to the coupled human–environment systems. Thus, Equation 3.4 show how vulnerability can be expressed as a function of exposure, sensitivity and adaptive capacity (Metzger et al., 2006).

$$Vulnerability = f\left[Exposure, Sensitivity, Adaptive\ Capacity\right] \qquad (3.4)$$

Potential impacts are a function of exposure and sensitivity as presented in Equation 3.5.

$$Potential\ Impact = f\left[Exposure, Sensitivity\right] \qquad (3.5)$$

Therefore, Equation 3.6 shows that vulnerability is a function of potential impacts and adaptive capacity:

$$Vulnerability = f\left[Potential\ Impact, Adaptive\ Capacity\right] \qquad (3.6)$$

The most vulnerable individuals or groups are those that (1) experience the most exposure to perturbations or stresses, (2) are the most sensitive to perturbations or stresses (i.e., most likely to suffer from exposure), and (3) have the weakest capacity to respond and ability to recover (Research and Assessment Systems for Sustainability Program, 2001).

(i) Potential impact assessment

According to Metzger (2006), potential impact is a function of exposure and sensitivity as shown in Equation 3.5. In terms of oil exploration and production activities a third function was included by the researcher to accommodate the risk posed by oil facilities. Therefore, PIA can be estimated from three main criteria;

1. The risk posed by oil facilities
2. Exposure of ecosystem and rural populace
3. Sensitivity of the landscape to pollution

Table 3.3 and Appendix C.1 (section B) summarize the sub-criteria for the main criteria.

Table 3.3: Criteria and sub-criteria for potential impact assessment

Criteria	Sub-criteria	Unit
Risk posed by oil facilities	Type of oil facility	index
	Age of oil facility	years
	Type of spill	index
	Estimated volume of spill	m^3
	Estimated area coverage of spill	m^2
Exposure of ecosystem and rural populace	Distance of oil facility to rural settlements	m
	Distance of oil facility to agricultural land	m
	Distance of oil facility to surface water bodies	m
	Distance of oil facility to forest	m
	Size of population affected	index
Sensitivity of the landscape to pollution	Topography	%
	Hydraulic soil property	index
	Depth to water table	m
	Geology	index

(ii) Adaptive capacity

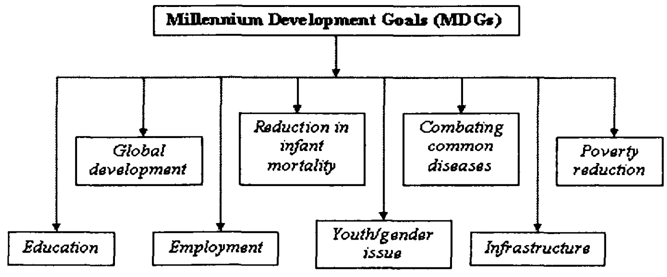
Adaptive capacity is the ability of households to anticipate and respond to changes in coastal ecosystems and to minimize, cope with, and recover from the consequences. The concept of adaptive capacity was introduced in the IPCC TAR (IPCC, 2001), according to which the factors that determine adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital (Metzger et al., 2006).

To develop suitable management strategies and prioritize specific sites, management planning should incorporate spatial differences in susceptibility (or vulnerability) to extreme events, hereafter termed environmental susceptibility (Clark et al., 2001). Similarly, management practices should also take into consideration socio-economic conditions that dictate the range of adaptations and management interventions possible in the face of environmental degradation. In particular, adaptive capacity indicates a community's potential to cope with disturbances and take advantage of new opportunities, whether due to climate impacts (IPCC, 2001) or conservation interventions.

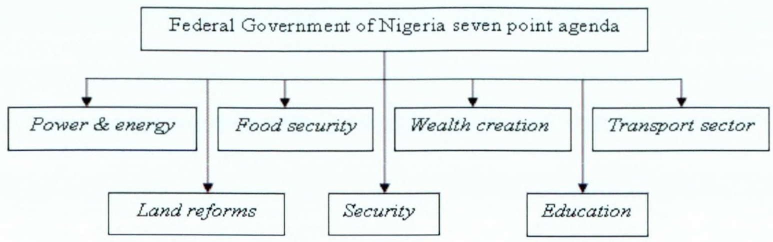
In order to ensure sustainable development and within the context of this research, the adaptive capacity was established by utilizing the UN eight point Millennium Development Goals (MDGs) and the Federal Government of Nigeria seven point agenda (FGNSPA) as displayed in Figure 3.10. At the United Nations Millennium Summit held in September 2000, 147 Heads of State adopted eight MDGs, which set targets to reduce poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women by 2015 (United Nations Development Programme, 2005). One of the eight MDGs is to ensure environmental sustainability, meeting human needs without undermining the capacity of the planet's ecological systems to support life over the long term (Gilman et al., 2006).

The MDGs have moved to the centre stage of the development debate and reducing poverty and deprivation has become a central challenge for policy makers (Klasen, 2008). They are the world's quantified targets for dramatically reducing extreme poverty and inequity over the course of a 15-year period (Clements et al., 2008).

FGNSPA was used in conjunction with MDGs for estimating the adaptive capacity index for vulnerability assessment and prioritising areas are shown in Figure 3.10(b). The FGNSPA was selected because it takes into consideration the socio-economic conditions that are vital to the existence of inhabitants of a place (Clark et al., 2001). According to Oker (2008), if the FGNSPA is well implemented, it will impact positively on the nation and place the economy on a path of sustainable growth.



(a)



(b)

Figure 3.10: Criteria for Adaptive Capacity (a) UN Millennium Development Goals (b) Federal Government of Nigeria seven point agenda

Human vulnerability can be established by quantifying and plotting the potentially impacted variables against their adaptive capacity. Figure 3.11 presents a novel framework to integrate these two considerations and give important insights into environmental planning and management strategies.

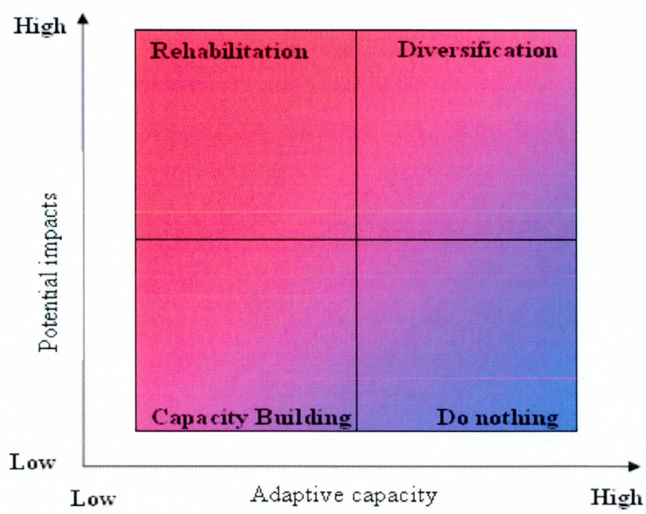


Figure 3.11: Human vulnerability assessment derived from potential impacts and adaptive capacity

From Figure 3.11, the following options can be deduced.

- Low Potential Impact/Low Adaptive Capacity

  Require capacity development through investments in poverty alleviation, infrastructure, social capital and alternative incomes.

- High Potential Impact/High Adaptive Capacity

Societal change and diversification is more likely. Diversification is an overarching strategy aimed at reducing risks and increasing options in the face of hazards used worldwide and across economic classes and political economies, in some cases at the cost of reduced material well being (Turner et al., 2003). Active ecosystem manipulation may be possible through remediation of soil and water and rehabilitation/relocation of affected inhabitants.

- High Potential Impact/Low Adaptive Capacity

Due to the potential impact of oil activities inhabitants will not have the resources/ability to adapt. This could lead to conflicts which would attract human disaster assistance, and donor aid with focus on reducing environmental impacts, increase capacity and reduce dependence on local natural resources.

- Low Potential Impact/High Adaptive Capacity

This scenario requires a do nothing situation although protected area management will also be appropriate.

3.5.1.2 Groundwater vulnerability assessment

Groundwater vulnerability assessment has been recognized for its ability to delineate areas that are more likely than others to become contaminated as a result of anthropogenic activities at/or near the earth's surface (Babiker et al., 2005). The vulnerability of aquifers to pollution is relatively easy to estimate because their transport characteristics do not change over time (Uricchio et al., 2004). Vulnerability is usually considered as an 'intrinsic' property of a groundwater system that depends on its sensitivity to human and/or natural impacts (Babiker et al., 2005). 'Specific' or 'integrated' vulnerability, on the other hand, combines intrinsic vulnerability with the risk of the groundwater being exposed to the loading of pollutants from certain sources (Vrba and Zoporozec, 1994).

Oil pollution is perhaps one of the worst environmental degradation associated with the oil industry. Some of the harmful effects of oil pollution include contamination of local aquifers, surface water bodies, inhibition to vegetation growth, reduction in biodiversity and health risks to humans and animals (Al-Adamat et al., 2003, Kwarteng, 1998, Luiselli and Akanni, 2003, Osuji and Nwoye, 2007). Groundwater quality assessment has been undertaken by a number of authors (Helena et al., 2000, Lin et al., 2006, Mendiguchia et al., 2007, Parinet et al., 2004, Singh et al., 2005). Some other authors focussed particularly on the Niger Delta region (Ajayi and Umoh, 1997, Akporido et al., 2000, Egboka et al., 1989, Ikem et al., 2002, Olobaniyi and Owoyemi, 2004, Udom et al., 1999).

At every point in the oil production, distribution, and consumption process, oil is invariably stored in storage tanks. Oil spills are natural consequence of petroleum exploitation and are generally speaking unavoidable (Adeyemi, 2004). The potential for an oil spill is significant, and the effects of spilled oil many times pose serious threats to the environment (Nadim et al., 2000). Leaking underground and oil pipelines, improper disposal of petroleum wastes, and accidental spills are major routes of soil and groundwater contamination with petroleum products in the Niger Delta region.

To provide guidance in evaluating the potential contamination from a given source, LeGrand developed an empirical point count system with five parameters namely, Depth to water table, Sorption above water table, permeability, water table gradient and Horizontal distance from a pollution source (especially from waste dump site) to a water well (Todd, 1980). Foster (1987) developed a rating vulnerability model that took into consideration ***G***roundwater occurrence, ***O***verlying lithology and ***D***epth to groundwater table (GOD). SINTACS was developed by Civita (1994). The most commonly used model is the DRASTIC model (Aller et al., 1987). DRASTIC methodology was originally developed by the USA Environmental Protection Agency and is one of worldwide used standardised systems for evaluation of groundwater vulnerability which can be used for the inter comparison of sites. The DRASTIC acronym stands for the seven hydrogeological parameters that are taken into account in calculating groundwater vulnerability and the parameter ratings are shown in Tables 3.4 and Table 3.5 respectively.

Table 3.4: Explanation of parameters for groundwater vulnerability assessment using DRASTIC model

Symbol	Description
D	Depth of Water
R	Net Recharge
A	Aquifer media
S	Soil media
T	Topography (slope)
I	Impact of the vadoze zone
C	Hydraulic Conductivity of the aquifer

The formula used to calculate a DRASTIC index is given by:

$$DRASTIC\ INDEX = D_W D_R + R_W R_R + A_W A_R + S_W S_R + T_W T_R + I_W I_R + C_W C_R \quad (3.7)$$

where the factors X_W are the weights for the different DRASTIC parameters and X_R are the ratings (scores).

Table 3.5: Parameter ratings for the DRASTIC model

	Parameters						
Rating Units	Depth (m)	Recharge (mm)	Aquifer (-)	Soil (-)	Topography (%)	Impact (-)	Conductivity (m/s)
1	>50	0-100	Shale	Clay	>18	Clay/Organic Soil	<E-08
2	45	100-200	Till	Shale	16-18		E-08
3	40	200-300	Silt	Silt	14-16		E-07
4	35	300-400	Schist	Schist/Till	12-14	Loamy Clay	E-06
5	30	400-500	Sandstone	Green rocks	10-12	Clayey Loam	E-05
6	25	500-600	Limestone	Sandstone	8-10		E-04
7	20	600-700	Green rocks	Limestone	6-8	Loam	
8	15	700-800	Sand	Sand	4-6	Sandy Loam	E-03
9	10	800-900	Sand & Gravel	Sand & Gravel	2-4	Loamy Sand	E-02
10	5	>900	Gravel	Gravel	0-2	Sand/Gravel	E-01

The derivation of relative importance (weights) as discussed in section 7.3 for groundwater vulnerability assessment was based on the DRASTIC parameters and as presented in Appendix C.2-section C.

3.5.1.3 Mangrove vulnerability assessment

The lowland forests especially the mangroves have come under serious exploitation and constant threat of disintegration in recent times. There are roughly 17 million ha of mangroves worldwide and are gradually depleting on a global scale (Gilman et al., 2006). Mangroves are known for their global environmental socio-economic value, currently occupying 14,653,000 hectares of coastal area worldwide (FAO, 2003) and providing several important functions for numerous species that are dependent on such ecosystems for their existence. They serve as breeding, spawning, hatching and nursery grounds for these benthic and pelagic marine species. Also a large number of endangered mammals, reptiles, amphibians and birds inhabit the mangroves (Benfield et al., 2005). With an economic value of the order of US$200,000-900,000 per ha (Wells et al., 2006), coastal inhabitants benefit directly and indirectly from the many services rendered by mangroves such as provision of food, timber, fuel and medicine (Giri et al., 2007). Additional benefits include improving coastal water quality and playing a key role in human sustainability and livelihood.

Despite their importance, mangrove vegetation like other marine ecosystems are now being threatened by a wide variety of natural threats (climate change, droughts, floods, land subsidence geologic erosion and sea level rise) and more recently human-induced (pollution, deforestation, invasion of exotic species, coastal development, saline water intrusion, sedimentation, sand mining, oil exploration and exploitation) processes. These processes damage the mangroves at alarming rates thereby diminishing the limited number of existing habitats. Over the past 50 years, about one-third of the world's mangrove forests have been destroyed. The cumulative effects of natural and anthropogenic pressures make mangrove wetlands one of the most threatened natural communities worldwide (Gilman et al., 2006). Therefore, there is urgent need to devise effective coastal mapping to monitor deforestation and degradation so as to develop conservation planning and management techniques to protect and also formulate recovery and restoration programs to safeguard this very fragile ecosystem.

Mangrove mapping provides the spatial information for mangrove vulnerability assessment but accurate mapping by ground survey is extremely difficult, time consuming and expensive as a result of remote and inaccessible nature of the terrain. Therefore, digital image processing and GIS technologies (see section 3.4) provide a rapid and cost-effective means of acquiring, storing and analyzing the necessary information. The role of remote sensing and geographical information system (GIS) technologies as well as other computer models in ecosystem management is indispensable (Sanwo and Arimoro, 2005). Satellite images in conjunction with Geographic Information System (GIS) provide effective tools. Habitat mapping of mangrove have been attempted by James et al. (2007) in the Niger delta region of Nigeria, Saleh (2007) in Abu Minqar Island located near the coastline of the Egyptian Red Sea, Giri et al.(2007) in Bangladesh and India and Benfield et al. (2005) in Punta Mala Bay, Panama, while vulnerability assessment of Vanuatu coastal areas has been conducted by Phillips (2000), while Gilman et al. (2006) particularly concentrated on mangrove vulnerability assessment to climatic change and sea level rise in the Pacific Islands.

When dealing with mangroves, researchers have developed the science and technology to quantify environmental degradation (Diop, 2003). However, there is deficiency in providing science-based solutions to decision makers, planners and managers who are more concerned with social and economic implications. Accurate predictions of changes to mangrove area and health, including those originating from climate change effects, enable advanced planning to minimize and offset anticipated losses and reduce threats to coastal development and human safety for specific sections of coastline (Gilman et al., 2006). Therefore, it becomes necessary to identify and estimate the relative importance of a number of socio-economic and environmental criteria to aid mangrove vulnerability assessment studies as presented in Appendix C.1-section D.

3.6 Computer Systems Components of Framework

It was necessary to incorporate a number of computer systems into the framework. These included two major components - digital image processing and statistical analysis.

3.6.1 Digital Image Processing

Monitoring the ever-changing temporal and spatial distribution of the Niger Delta environment has become a necessity that can be addressed through the use of remote sensing images. Such images are used to determine important indicators/criteria such as landcover classes and landscape changes that have occurred that can be incorporated into MCDS framework. Also, the extent and location of visible spillage and release, vegetation damage, and the threats to natural drainage and human welfare can be extracted from satellite images(Lillesand et al., 2004). The development of modern earth observation techniques, such as the United States of America's - Landsat, IKONOS, Quickbird sensors, France's - SPOT, Nigeria's - NigeriaSat and India's IRS, with particular reference to multi-spectral/temporal remote sensing data greatly enhances the mapping and monitoring possibilities of the earth's features.

Existing conventional methods for environmental field survey over large area are laborious, time and financial consuming. Specifically, they lack the real-time spatial overview that is necessary for large degraded areas. Satellite remote sensing provides suitable ways for resource mapping, monitoring and managing environmental changes (Coppin et al., 2004), using optical and microwave imagery from various kinds of sensors (Lillesand et al., 2004). Its strength lies in the wide synoptic coverage, which provides consistent data over large areas through orbiting satellites having different wavelengths, look angles and resolutions (Kwarteng, 1999). Repeatability of data also plays a role in ensuring their usefulness. Therefore, the spatial, spectral and temporal resolutions of remote sensing data are of utmost importance in environmental studies.

The increasing availability of modern technology such as satellite imagery, geographic information and analysis systems are tools that allow the production of reliable spatial (statistical) data (Jansen and Di Gregorio, 2003). Remote sensing deals with the knowledge and techniques used to analyse, interpret, monitor and manage environmental changes, using optical and microwave imagery from various kinds of sensors (Kabanza et al., 2001). It provides spatially consistent data sets that cover large areas with both high spatial detail and high temporal frequency (Chen et al., 2006). The underlying premise for using remote sensing data is that a change in the status of an object must result in a change in radiance value (Al-Quraishi et al., 2004, Hall and Hay, 2003, Mas, 1999).

Environmental studies using remote sensing data of Nigeria, over a twenty year period has been reported by Arimoro (2002). Before remote sensing data is used, it has to be processed to eliminate inherent noise as a result of differences in atmospheric absorption and scattering (Coppin and Bauer, 1996). Geometric distortion can also affect the quality of the image. Digital image processing involves the manipulation of data with the aid of a computer (Lillesand et al., 2004).

Satellite based sensors hold the potential to detect, identify and map changes in the environment as a result of their synoptic and repetitive data acquisition capabilities. Remote sensing thus provides a viable source of data from which environmental changes can be updated, extracted efficiently and cheaply (Mas, 1999). The data so collected is used to complement the ground-based data but not to replace them as each has its strengths and weaknesses. Attempts to use satellite remote sensing for oil spill detection continue, although success is not necessarily as claimed and is generally limited to identifying features at sites where known oil spills have occurred (Fingas and Brown, 2000).

Land cover classification and change detection have been conducted by (Mundia and Aniya, 2006, Yang and Lo, 2002) using unsupervised ISODATA classification algorithm. (Wu et al., 2006) applied the maximum likelihood method for the land use classification. In Nigeria, supervised classification has been used to monitor land use dynamics in south-western region (Akinyemi, 2005), while Ojigi (2006) compared different supervised classification algorithms to monitor landscape changes in Abuja. His findings reveal that the maximum likelihood algorithm performed better than the other methods used. This research introduces a hybrid classification technique that combines integrates the supervised and unsupervised classification methods thus improving the overall accuracy of landcover classes. Furthermore, thematic information derived from the geology/geomorphology was applied for more accuracy improvement.

This section therefore addresses the use of remote sensing data to determine land cover classes and also to study temporal/spatial land changes that have occurred. The research approaches the use of remote sensing data from their ability to discriminate landscape changes in the environment as a result of natural and anthropogenic activities. The digital image processing sequence for land cover classification and change detection using remotely sensed data is shown in Figure 3.12.

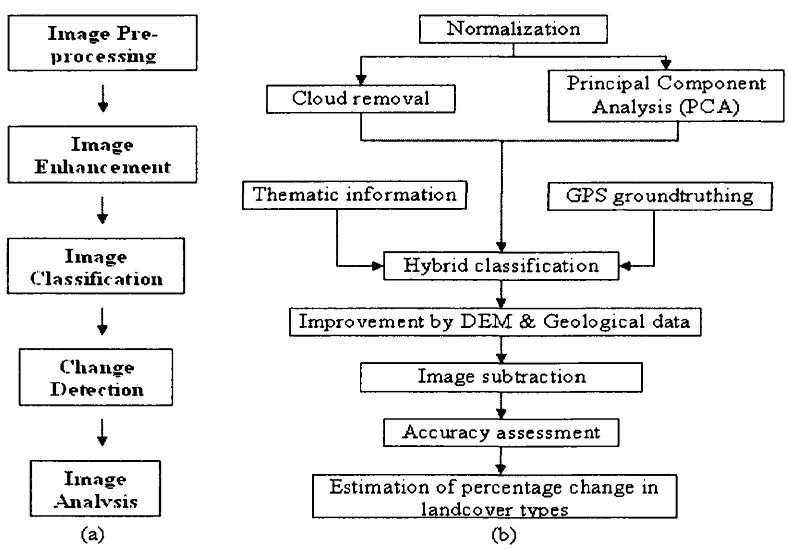


Figure 3.12: Digital image processing and change detection sequence (a) generic steps (b) steps applied in this research work

3.6.1.1 Image pre-processing

A significant step in comparing multispectral remote sensing images is pre-processing (image rectification and restoration). Pre-processing of satellite sensor images prior to actual change detection is essential and has as its unique goals, the establishment of a more direct linkage between the data and biophysical phenomena, the removal of data acquisition error and image noise, and the masking of contaminated (e.g. clouds) and/or irrelevant (e.g. water bodies) scene fragments (Coppin et al., 2004). The major pre-processing steps are shown in Figure 3.13.

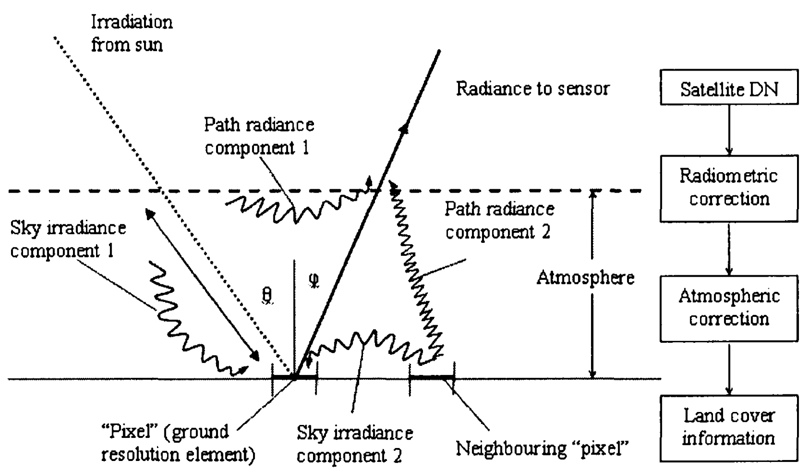


Figure 3.13: Atmospheric effects in determining various paths of energy that reaches back to the sensor

3.6.1.1.1 Geometric corrections

Raw digital data often contain geometric distortions so significant that they cannot be used directly as a map base without further processing (Lillesand et al., 2004). Jensen (2005) recognised two types of geometric errors typically exhibited by remotely sensed images – internal and external geometric error. Orthorectification is also a process by which the geometric distortions of the image are modelled and accounted for, resulting in a planimetrically correct image. The process yields map-accurate images, which can be highly useful as base maps and may be easily incorporated into a GIS. The final orthorectified images already executed by NASA have a root mean square (RMS) geodetic accuracy of better than 50m (Tucker et al., 2004).

3.6.1.1.2 Radiometric correction

Image rectification and correction concentrates on the removal of radiometric and atmospheric distortions of optical and near-infrared imagery (Figure 3.13). Radiometric correction involves senor correction and calibration. Sensor correction addresses the problem of radiometric differences between sensors caused by their variability in the sensitivity of detectors. Additionally, data from the same sensor will yield different digital numbers during the lifetime of a satellite system. Therefore it is necessary to convert digital number values (DN) into physical meaningful units referred to as "reflectivity" [0-100%]. Depending on the application, radiometric calibration can be absolute or relative (Chen et al., 2005b). As image obtained are sometimes already radiometrically calibrated DN values, Equation (3.8) can be used to convert *DN* values to radiance values (*L*) for the Landsat TM image.

$$L_{satTM} = (DN \times G_{bt}) + B_{bt} \qquad (3.8)$$

Where L_{satTM} is spectral radiance detected by a satellite sensor; *DN* is the digital number of the sensor measurement, and *B* is the bias or offset that compensates for the shift from 0 radiance value for a specific band (b) at a specific period in the life cycle of the satellite sensor (t) and *G* is the slope (gain) of the conversion function. This is only valid for the same band (b) and same period in the life cycle of the satellite sensor (t).

Radiometric normalization is used reduce atmospheric effects between dates. It is an image based correction method achieved by setting the multi-temporal images into a common scale without extra parameters from other measurements (Chen et al., 2005b). A number of methods exist for normalizing images; the most common involves using the reflectance of invariant targets within multiple scenes can be used to render the scenes to appear as if they were acquired with the same sensor, with the same calibration, and under identical atmospheric conditions, without the need to be absolutely corrected to surface reflectance.

This research was expected to apply absolute radiometric correction to the satellite image using field spectroscopy equipment belonging to the Nigerian Aerospace organisation, NARSDA in December 2007, but this was aborted at the last minute due to security issues surrounding the Niger Delta region. The researcher was left with no option than to apply a change detection method that was unaffected by radiometric error, that is the simple band subtraction method.

3.6.1.2 Image classification

Image classification is an important part of the remote sensing, image analysis and pattern recognition. The basic objective of data analysis is to separate the information contained in the dataset into an exhaustive set of non-overlapping region, corresponding as precisely as possible to data points belonging to the particular classes desired. In some instances, the classification itself may be the object of the analysis. The overall objective of image classification procedures is to automatically categorise all pixels in an image into land cover classes or theme (Lillesand et al., 2004). The image classification therefore forms an important tool for examination of the digital images.

At present, there are different image classification algorithms, which can be grouped into two; unsupervised and supervised classifications. Unsupervised classifications also known as clustering algorithms are focused upon finding classes of data that are separable.

3.6.1.2.1 Unsupervised classification

The basic assumption in unsupervised classification is that values with a given cover type should be close together in the measurement space, whereas data in different classes should be comparatively well separated (Lillesand et al., 2004). The number of classes is the most significant of the clustering parameters (Yang and Lo, 2002).

If too small, relatively broad clusters may be generated which may not produce true results. If the number is too big, very pure clusters may be yielded with highly demanding computational resources and substantial increase in time required for cluster labelling (Mundia and Aniya, 2006). The resulting clusters do not necessarily have any relationship with the classes of informational value they only assist in obtaining a list of classes that are exhaustive. Therefore, the results of the classification must be compared to some reference data for meaningful interpretation.

3.6.1.2.2 Supervised classification

Supervised classification algorithms focus upon classes of informational value. However, the classes initially so defined are not necessarily separable. Thus some combined or iterative use of unsupervised and supervised classification is required. This is necessary because although the unsupervised method can be comparable with guess work the results obtained can aid the separation of landcover types obtained from the supervised classification (see section 5.2.2.2). Additionally, thematic information such as geology/geomorphology can also help in decimating among the different landcover classes.

3.6.1.3 Change detection algorithms

During the last three decades, a large number of change detection methods have evolved that differs widely in refinement, robustness and complexity (Hall and Hay, 2003). These methods often involve change extraction and change classification and include, image overlay, image differencing, image ratioing, image regression, tassled cap transformation, chi-square transformation, post classification comparison and principal component analysis. Ridd and Liu (1998), from their study using some of the above mentioned algorithms, showed that there was no algorithm that had superiority over the others.

The change detection algorithm applied in this research was image differencing which involves the subtraction of two classified images (refer to section 5.2.4 for more details). The advantage of this method is that the images do not have to be corrected for atmospheric effects, since the images were collected within the same phenological period. The main disadvantage is that the accuracy of the results is dependent on those of the classified images.

Environmental change detection of the Niger Delta region using remotely sensed data has been conducted by Niger Delta Environmental Survey, (1997) using a post-classification change detection procedure. While Osei *et al.* (2006) utilized results from unsupervised classification for detecting changes in the region.

3.6.2 Statistical Analysis

Two kinds of statistical analyses are proposed framework for integration into the framework. Depending on the sampling procedure (biased or unbiased) and type of sample (quantitative or qualitative), data collected can be parametric or non-parametric. The research utilized parametric data (physico-chemical variables) for soil and water analysis, while non-parametric data (weights and scores of identified criteria) was extracted from questionnaire survey.

Among the important information required in assessing the level of contamination is the quality of soil and water (surface and groundwater) with the vicinity of spill sites. With the persistent problems arising from oil activities, the ability to meet soil and water environmental standards in the area is proving to be a big challenge.

The quality of surface and groundwater within a region is governed by both natural processes (such as precipitation rate, weathering processes and soil erosion) and anthropogenic effects (such as urban, industrial and agricultural activities, and the human exploitation of water resources). Protection of water quality attempts to achieve, through criteria and standards and their implementation, the water quality goals of a specific water body for its designated use or uses (Russo, 2002).

Despite interpretational problems, total petroleum hydrocarbons (TPH) as a lumped parameter can be easily and rapidly measured or monitored, thereby making it an accepted regulatory benchmark used widely to evaluate the extent of petroleum product contamination. But the exorbitant cost of its analysis invites the need of a statistical approach that first examines the relationship among soil and water variables with a view of extracting those that can readily be associated with oil spill for utilization in the proposed framework. This can be achieved through the application of principal component analysis. Secondly the approach will help to establish the processes (natural or anthropogenic) responsible for the concentration of measured constituents to aid decision makers in impact assessment. Such information is also vital in the prioritization of contaminated areas (refer to Chapter 8).

Multivariate statistical methods such as principal component analysis and factor analysis were used to reduce the redundancy of physico-chemical constituents of surface and groundwater, thereby emphasizing those parameters that are enhanced due to oil spill. The spatial distribution of physico-chemical constituents of surface and groundwater was established using cluster analysis.

3.6.2.1 Parametric statistical analysis

Soil and water quality data sets were subjected to multivariate analysis: cluster analysis (CA) and principal component analysis (PCA)/factor analysis (FA). These analyses required a preliminary step of the treatment of data which consisted of the normalization of the raw analytical data, so as to avoid misclassifications due to the different order of magnitude and range of variation of the analytical parameters (Aruga et al., 1995). The multivariate methods utilized are summarized below.

3.6.2.1.1 Principal component analysis and factor analysis

PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables (Shrestha and Kazama, 2007). The processes governing FA and PCA are similar except in the preparation of the observed correlation matrix for extraction and in the underlying theory (Tabachnick and Fidell, 2007). PCA is thus concerned only with establishing which linear component exists within the data and how a particular variable might contribute to that component (Field, 2005). The principal components (PC) can be expressed as:

$$z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \ldots + a_{im}x_{mj} \qquad (3.9)$$

where z is the component score, a is the component loading, x the measured value of variable, i is the component number, j the sample number and m the total number of variables.

Factor analysis yields the general relationship among measured chemical variables by showing multivariate patterns that may be help to classify the original data (Liu et al., 2003). Two categories of factor analysis exists – exploratory and confirmatory (Howitt and Cramer, 2005). Exploratory factor analysis was used in this study and it allows for the understanding of a complex set of variables by reducing them to smaller number of factors. Factor analysis takes data contained in a correlation matrix and rearranges them in a manner that better explains the structure of the underlying system that produced the data. Therefore, the correlation coefficient matrix measures how well the variance of each constituent can be explained by relationships with each of the others. Then, the variances/co-variances and correlation coefficients of the variables are computed. The correlation coefficient is

$$r_{x,y} = \frac{\sum(x - x_m)(y - y_m)}{\sqrt{[\sum(x - x_m)]^2[(y - y_m)]^2}} \qquad (3.10)$$

In this equation the correlation coefficients ($r_{x,y}$) is simply the sum (over all samples) of the products of the deviations of the x-measurements and the y-measurements on each sample, from the mean values of x and y, respectively, for the complete set of samples (Liu et al., 2003). The main purpose of FA is to reduce the contribution of less significant variables and simplify even more of the data structure (Shrestha and Kazama, 2007). The equation for FA is

$$z_{ij} = a_{f1} f_{1i} + a_{f2} f_{2i} + a_{f3} f_{3i} + \ldots + a_{fm} f_{mi} + e_{fi} \tag{3.11}$$

where z is the measured variable, a is the factor loading, f is the factor score, e the residual term accounting for errors or other source of variation, i the sample number and m the total number of factors. The terms 'strong', 'moderate', and 'weak' as applied to factor loadings, refer to absolute loading values of >0.75, 0.75–0.50 and 0.50–0.30, respectively (Liu et al., 2003).

3.6.2.1.2 Cluster analysis

The purpose of cluster analysis is to identify groups or clusters of similar sites on the basis of similarities within a class and dissimilarities between different classes (Sparks, 2000). It is an unsupervised pattern recognition technique that uncovers intrinsic structure or underlying behaviour of a data set without making a priori assumption about the data, in order to classify the objects of the system into categories or clusters based on their nearness or similarity (Panda et al., 2006). Agglomerative hierarchical clustering is the most commonly used method where clusters are formed sequentially, by starting with the most similar pair of objects and forming higher clusters step by step. Cluster analysis was applied on experimental data standardized through z-scale transformation in order to avoid misclassification due to wide differences in data dimensionality (Liu et al., 2003). Standardization tends to increase the influence of variables whose variance is small and reduce the influence of variables whose variance is large (Singh et al., 2004). Furthermore, the procedure eliminates the influence of different units of measurement and renders the data dimensionless.

3.6.2.2 Non-parametric statistical analysis

Socio-economic data obtained from the questionnaire survey were subjected to non-parametric statistical analysis to establish level of significance of selected criteria.

3.6.2.2.1 Grouped median

When reporting results from a non-parametric questionnaire survey, it is relevant to note that the mean and standard deviation which is usually associated with normal distributed sampling is not applicable. The median and range are used instead (Field, 2005). For the derivation of the central tendencies for score and weight the grouped median (GM) was calculated using the equation

$$GM = L + I * \left(\frac{N/2 - F}{f} \right) \tag{3.12}$$

where:

L = lower limit of the interval containing the median
I = width of the interval containing the median
N = total number of respondents
F = cumulative frequency corresponding to the lower limit
f = number of cases in the interval containing the median

This central tendency has the advantage over the median value as it allows one to recognize that, for example, a 5-point rating scale constrains responses to a small set of discrete values when the underlying attribute being measured is really a continuous scale.

3.6.2.2.2 Mann-Whitney – Wilcoxon test

The Mann-Whitney (independent) and Wilcoxon (paired) tests which are equivalents of the t-test were applied for qualitative information obtained from questionnaire survey (section 7.2.4). The advantage of using these tests is that they do not assume a normal distribution.

3.7 Decision Support Systems

The management of natural resources requires the integration of often very large volumes of disparate information from numerous sources; the coupling of this information with efficient tools for assessment and evaluation that allow broad, interactive participation in the planning, assessment, and decision making process; and effective methods of communicating results and findings to a broad audience (Fedra and Feoli, 1994). Therefore, the driving force in the development of Decision Support System (DSS) is the need to integrate qualitative and quantitative information and the inclusion of scientifically assessed risk in decision-making pushes planning processes towards including more complex, subjective and complicated choices (Mysiak, 2004). The methods, criteria and values that are used by groups and individuals to help them make decisions can have a significant influence on the decision, and on how others view the decision process and outcomes (Meacham, 2004).

In the last decades, mathematical/statistical models, numerical algorithms and computer simulations have been used as the appropriate means to gain insight into environmental management problems and provide useful information to decision makers (Poch et al., 2002). The concept of DSS emerged in the 1970s, as a family of computer systems in the field of decision theory, showing great potential in the field of environmental management in dealing with semi-structured and unstructured problems (Giupponi, 2007). In the last decades, numerous DSSs have been developed for water resource management, in which increasingly sophisticated computerised systems integrate watershed processes operating at different spatial and temporal scales, simulation models, and decision-making approaches. These tools have been developed for a variety of purposes, such as flood water spreading site selection (Zarkesh, 2005), economic and environmental impacts of land-use change (Dunn et al., 1996), irrigation schemes (Mira da Silva et al., 2001), water resource management (Mysiak et al., 2005), Information technology, and in particular, the integration of data base management systems, GIS, remote sensing and image processing, simulation and multi-criteria optimization models, expert systems, and computer graphics provide some of the tools for effective decision support in natural resources management (Fedra and Feoli, 1994). The decision support system (DSS) provides a framework through which decision-makers can obtain the necessary assistance needed for making decisions through an easy-to-use menu or command system. Generally, a DSS will provide help in formulating alternatives, accessing data, developing models and interpreting their results and by selecting options or analyzing the impacts of a selection. The role of a decision support system is to assist the decision maker in selecting the 'best' alternative from among the number of feasible alternatives (Jankowski, 1995).

3.7.1 Decision support systems and multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) is a family of methods commonly implemented by decision support systems (DSS) to compare alternative courses of action on the basis of multiple factors, and to identify the best performing solution (Geneletti and van Duren, 2008). Decision-support is not decision-making. A decision-support system is not designed to, and often does not have the capacity to, find an optimal solution. It is not a substitute to the considered opinion of the decision-maker; these systems do not make decisions. Rather, they provide decision-makers with a process to gather and display the required data in a clear and transparent framework. A DSS is a customized, interactive and flexible computing environment that integrates models/analytical tools, databases, graphical user-friendly interfaces, expert knowledge and other systems (Levy, 2005).

MC-DSS such as GeoChoicePerspectives has been successfully used for habitat site selection in the Duwamish Waterway area situated in the state of Washington (Jankowski et al., 1997). Open Spatial Decision Making (OSDM), is an Internet-based MC-SDSS designed to support the selection of suitable sites for radioactive waste disposal by the public in Great Britain (Carver, 1996). The integration of

DPSIR framework (section 3.2) and MCDA (section 3.3.3.2) in a DSS is different from conventional MCA problems. As earlier stated, in spatial decision-making the options are represented as maps with collection of points, lines and areal objects and associated attributes (Fassio et al., 2005). Each map therefore gives an option criterion outcome, representing the performance of an option with regards to a criterion. Thus, Figure 3.14 provides the procedure for transforming spatially distributed indicators into single values in order to fit into a two dimensional decision matrix (options x criteria) by various extraction procedures (Fassio et al., 2005).

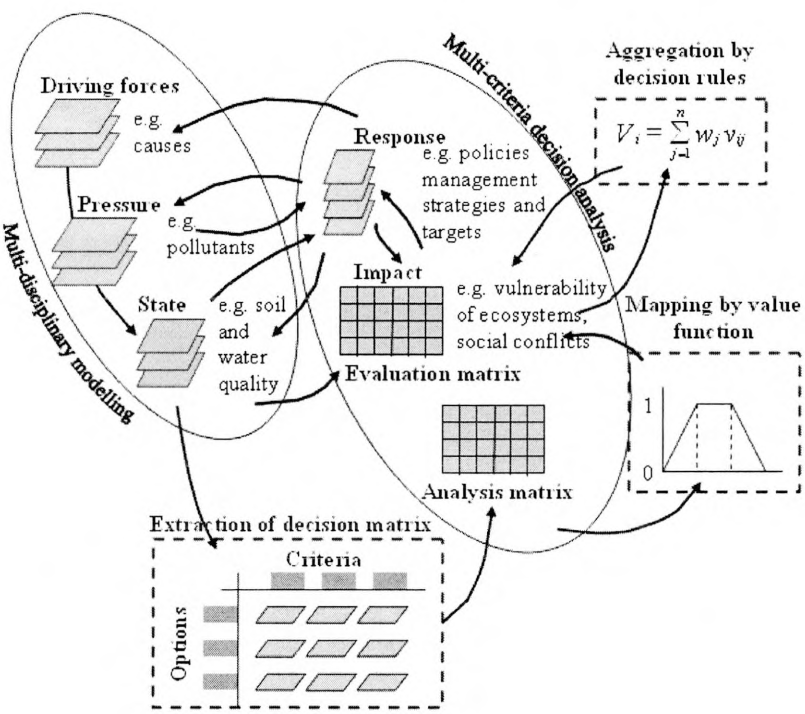


Figure 3.14: Integration of DPSIR framework and MCDA in the DSS for prediction of decision outcomes, exploration and aggregation of the preferences of decision makers

3.7.2 Environmental decision support systems (EDSS)

Development of environmental decision support systems (EDSS) is rapidly progressing (Matthies et al., 2007). EDSS is an intelligent information system that helps reduce the time in which decisions are made, and improves the consistency and quality of decisions (Poch et al., 2002). The authors further stated that decisions are made when a deviation from an expected, desired state of a system is observed or predicted. This implies a problem awareness that in turn must be based on information, experience and knowledge about the process. Those systems are built by integrating several artificial intelligence methods, geographical information system components, mathematical or statistical techniques, and environmental ontologies as displayed in Figure 3.15. An EDSS often consists of various coupled environmental models, databases and assessment tools, which are integrated under a graphical user interface (GUI), often realized by using spatial data management functionalities provided by geographical information systems (GIS) (Matthies et al., 2007).

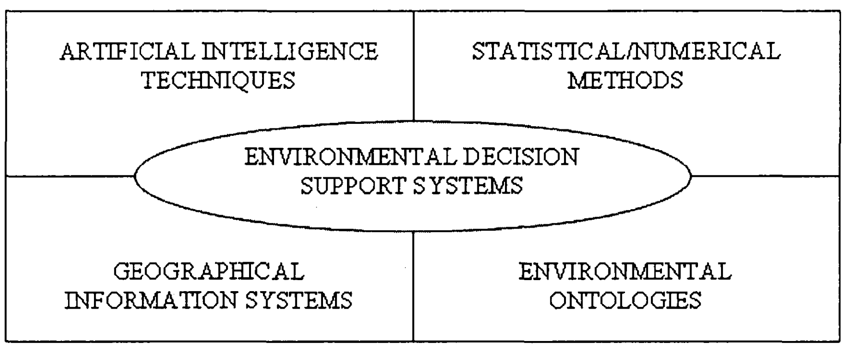


Figure 3.15: **EDSS conceptual components (Poch et al., 2002)**

3.7.3 Geographic information systems (GIS) and spatial decision support systems (SDSS)

In recent years, considerable interest has been focused on the use of Geographic Information Systems (GIS) as a decision support system (Eastman, 1999, Geneletti, 2004). The primary aim for the development of Geographical Information Systems (GIS) is for the spatial management of database (van der Meulen, 1992). GIS is limited as a decision support tool when handling complex, multifaceted, ill-structured social problems. It also lacks the capability for choice modelling which is very useful in decision making for environmental planning and management. The missing link between GIS and SDSS techniques is the absence of planning/policy analysis methodology in GIS which enables decision makers to consider multiple agendas, evaluate multiple decision criteria and select alternatives most closely aligned with their priorities (Akinyemi, 2004). This demands for the integration of GIS and DSS in a flexible manner to enable the input of weights and human choice or judgement into the decision making process (Akinyemi, 2004, Enache, 1994). Two approaches have been used to improve the decision-making capabilities of GIS. In the first approach relevant decision making tools are developed within the GIS (Eastman et al., 1995), while in the alternative approach, GIS is coupled with other general software packages (statistical) or with specialised analytical models such as environmental or socio-economic models (Jankowski, 1995).

Integration of GIS in multi-criteria analysis has been done by a number of authors. Atkinson *et al.* (2005), applied GIS based methodology that combines least cost path (LCP) analysis on a continuous surface and MCA to facilitate route generation based on multiple environmental and economic criteria. Chen et al. (2001) developed a MCE-RISK for risk decision making in natural hazards. Kontos et al.(2005) and Mahini and Gholamalifard (2006), presented a MSW landfill siting methodology with the combined utilization of GIS and MCA methods. The MCDS framework being proposed in this research will integrate MCA, remote sensing and statistical techniques in the vulnerability assessment and prioritization of contaminated sites.

3.7.4 DSS frameworks in related fields

A number of DSS frameworks have been developed in different fields. They include the DEcision Support sYstem for the REqualification of contaminated sites (DESYRE) DSS, founded by Italian Ministry for University and Scientific Research was develop to address problems related with contaminated macro-sites rehabilitation in three main fields: site characterization and data processing, evaluation of the risk, choice of proper remediation technologies (Carlon et al., 2008, Critto et al., 2002). (Dragan et al., 2003) presented established methodology of spatial decision support systems (SDSS) integrated in a GIS to reduce erosion rates. The MULINO Decision Support System for sustainable use of water resources at catchment scale (Fassio et al., 2005, Giupponi, 2007, Mysiak et al., 2002). NELUP decision-support system (DSS) was developed to provide a quantitative description of the main economic and environmental impacts arising out of rural land-use change at the river-basin scale (Dunn et al., 1996) and the management of petroleum contaminated sites (Geng et al., 2001). The GIS-based decision support system (DSS)—drainage runoff input of pesticides in surface water, DRIPS—has been developed on behalf of the German EPA (UBA) for exposure assessment of agriculturally used pesticides in surface waters (Ropke et al., 2004). The MicroLEIS DSS system was developed to assist specific types of decision-makers faced with specific agro-ecological problems (De la Rosa et al., 2004). This research emerges with a structural framework on which a DSS for vulnerability assessment and prioritization of contaminated areas can be constructed.

3.7.5 DSS software applications

In this section a number of recently developed DSS designed specifically for natural resource and land-use management are discussed with regards to their possible application to environmental decision-making. They include DEFINITE (Janssen et al., 2001) and ILWIS (Boerboom et al., 2004) and Idrisi (Eastman, 2001).

DEFINITE (Janssen et al., 2001) is a high-end multi-objective decision-support tool. It is a modular program with much functionality. The problem definition module includes the ability to construct hierarchies and to evaluate the options by direct assessment or by pairwise comparison, as well as checks for dominance (when one option is outperformed against every criterion by other options), and also correlation analysis on the criteria. The multi-criteria analysis module includes many aggregation and weighting techniques (most of those detailed early in this chapter). DEFINITE includes a cost-benefit analysis module as well as a sensitivity analysis module. DEFINITE is designed to run on the Microsoft Windows operating system and uses other Microsoft products extensively for importing and exporting analyses and reporting analyses. The high level of functionality has both costs and benefits. The user interface is cluttered and complicated to follow and use. This is a tool for researchers and policy workers and not for community groups

ILWIS stands for the Integrated Land and Water Information System. It is a Windows-based, integrated GIS and remote sensing application. Release 3.2 (January 1st 2004) contains a new spatial multi-criteria analysis (SMCE) module, which is an extension of the raster operations. What turns the GIS into a spatial planning and decision support module is the addition of methods to subjectively interpret data and the importance of various data sources (Boerboom et al., 2004).

Idrisi GIS and Image Processing software was developed by Professor J. Ronald Eastman of Clark Lab and was first released in 1987. The software has applications in areas such as:

- Multi-criteria and multi-objective decision making
- Environmental change and time series analysis
- Land cover change, change prediction and analysis of ecological implications
- Dynamic modelling
- Risk and uncertainty management
- Soft classification of remotely sensed imagery

3.8 Summary

This chapter has provided an insight into the concepts and tools that are required in the development of the proposed MCDS framework. Due to the conditions and problems outlined in the first part of the literature review it became necessary to develop a multi-criteria analytical decision framework. The framework was structured in accordance with a modified version of DPSIR.

Although EIA studies have unconnectedly used some of the tool and concepts outlined, the incorporation of remote sensing methods, geographic information systems (GIS), multivariate statistical analysis and multi-criteria analysis (MCA) in a decision framework for EIA is a new approach especially for post developmental activities such as vulnerability assessment and prioritization of contaminated sites.

The subsequent chapter outlines the data sets required and methodology for the development of the framework.

Chapter 4 : Data and Methods

4.1 Introduction

This chapter describes the data and methods applied in the development and evaluation of the MCDS framework (refer to section 3.7). The framework utilizes a multi-tool approach capable of managing interrelated elements such as environmental processes as well as socioeconomic factors that affect a region or specific natural resource under a single unifying approach, through the collaboration of stakeholders, in order to conserve biodiversity and protect ecological integrity, and to sustain the provision of valued services and products.

The development of appropriate and effective tools for decision making requires an understanding of the contexts within which these decisions are made. The complexity of the problem necessitated the utilization of a combination of discrete, continuous and spatial information in a management framework, for proposing, prioritising and managing solutions to the problems arising from oil production in concerned communities in the Niger Delta region.

4.2 Data Acquisition

The MCDS framework required various forms of data as displayed in Figure 1.1. These were separated into two groups – preliminary and field data.

4.2.1 Preliminary data

At the early stage of the research work, it was necessary to travel to Nigeria to collect existing data from various Nigerian organisations. Historic data including physico-chemical, heavy metal and hydrocarbon parameters of water, soil and sediments were obtained from a number of laboratories in Warri Delta State as shown in Table 4.1 (some laboratories that had ethnical issues with the listing of names of such organisations were exempted from the list). Most of the laboratory results could not be utilized because of different instrumentation and procedures used for analysing the samples. Only the set of data obtained from Michary laboratory was used in combination with those collected by the researcher during the course of study.

Table 4.1: List of laboratories consulted for historic data on soil and water

Laboratory	Type of Sample		
Themosteel	Water	Soil	Sediment
Tudaka	Water	Soil	Sediment
Global Environmental	Water	Soil	Sediment
Michary	Water	Soil	Sediment

The Department of Petroleum Resources is solely responsible from oil spill information in Nigeria. Details of oil spill information are presented in Table 4.2. Socio-economic information was obsolete and where available, was difficult to obtain. A way to overcome such shortcoming was to carry out a questionnaire survey to obtain required information.

Table 4.2: Oil spill data from DPR

SN	SPILL NAME	DATE OF SPILL	CAUSE OF SPILL	QTY SPILL (in barrels)
1	Olomoro/Oleh Compressor Station	02/06/2002	Sabotage	10
2	Sapele W6 Flowline	10/01/2002	Production Equipment Failure	25
3	6" Isoko Deep bulkline Spill	07/07/2002	Sabotage	20
4	Kokori W 38T Spill @ Kokori Community	30/08/2003	Sabotage	14
5	Kokori W 9S Spill @ Kokori Community	16/10/2003	Sabotage	110
6	Uzere East W26L Spill @ Uzere Community in Isoko	05/08/2002	Sabotage	16
7	Uzere W19L Spill @ Uzere community	13/04/2002	Production Equipment Failure	20
8	Ogini Knock Out vessel @ Ogini community in Isoko	18/07/2003	Production Equipment Failure	12
9	Uzere W10L Wellhead	27/10/2003	Sabotage	135
10	Kokori W15L	16/10/2003	Sabotage	150
11	6" Isoko Deep Bulkline Spill	07/07/2002	Sabotage	20
12	Ajatiton W1S	18/07/2003	Sabotage	25
13	Uzere W9s	10/10/2003	Sabotage	30
14	Kokori W5T	06/10/2003	Sabotage	853
15	Ubefan W40 @ Ubefan	06/02/2002	Sabotage	20
16	Odidi W46	23/02/2002	Sabotage	10
17	Otumara W15	31/07/2003	Sabotage	1000
18	Yokri Flow Station	02/06/2002	Corrosion	-
19	Akono W1	25/02/2002	Sabotage	14
20	Opukushi W/N5S	23/06/2003	Sabotage	12

SN	SPILL NAME	DATE OF SPILL	CAUSE OF SPILL	QTY SPILL (in barrels)
21	Opukushi W25T spill @ Opukushi	02/05/2003	Sabotage	40
22	Opukushi W34	03/10/2003	Sabotage	10
23	Kanbo 3S Spillage	11/05/2003	Sabotage	20
24	Opukushi W25T Spill	16/06/2003	Sabotage	10
25	12' Benisede-Isampou TL @Ekeremor	19/02/2002	Sabotage	50
26	16" Opukushi-Isampou TL @ Torugbene	27/05/2002	Production Error	120
27	24" Amukpe-Rapele TL Spill @ Adjakimoni	07/07/2002	Sabotage	450
28	12" Benisede DL @ Foutougbene BVS Manifold	28/10/2002	Sabotage	100
29	24" Trans Ramos Pipeline Laek @ Aghoro/Ogbotobo	01/11/2002	Sabotage	22
30	20"/24" Crude Oil TL Leak @ Maroko near Warri	28/11/2002	Production Equipment Failure	250
31	Isampou-T manifold @ Angalaweigbene	14/02/2003	Sabotage	60
32	8" Batan Tie-In Manifold Spill	20/10/2002	-	300
33	12" Benisede Delivery Line @ Torugbene Community	-	Sabotage	900
34	16" Isampou-Opukushi TL Spill @ Amabolou	18/06/2003	Sabotage	-
35	16" Eriemu-UQCC TL Spill @	18/06/2003	Sabotage	50
36	24" UQCC-Amukpe TL Spill @ Uvwiamuge	07/05/2003	Sabotage	1000
37	16" Utorogu-Isampou TL Spill @ Oviri-Olomu	14/07/2003	Sabotage	600
38	24' UPS-Rapele Tl Spill @ Orhere Agbarho	21/08/2003	Sabotage	400

Due to the sensitive nature of some of the thematic information (e.g. pipeline layout, oil wells and flowstations) required for this research, it was decided to seek the authorization of the Department of Petroleum Resources (DPR) before any oil company could provide such sensitive information, as shown in Appendix A.5. Electronic maps containing vital information on location of oil facilities such as pipelines, flowstations, were then provided by Shell Petroleum Development Company (SPDC) as presented in Appendices A.2.3 and A.2.4. The information provided in this study, was such that the exact locations of oil facilities were not displayed due to ethical issues. SPDC was approached for thematic information for this research as they control over 50% of oil related activities in Nigeria. The information on location of oil facilities provided by SPDC was randomly checked by the researcher during field visits.

Hard copy remote sensing data such as black and white aerial photographs and thematic maps covering the whole of Nigeria were also collected from the Nigerian Federal Surveys. These were not used, due to their poor information content. Secondly, the information could not be converted to electronic format due to the absence of a digitizer. SPOT satellite images from the French satellite imagery provider were obtained from SPDC, although they were of medium spatial resolution, they were not used as they only covered less than 50% of the study area.

The National Space Research and Development Agency (NASRDA) was approached for satellite images from Nigeria-sat-1. Unfortunately, the available image which was found to be the most recent (acquired in 2005) was also unusable, as features appeared blurred and could not be readily identified. The Nigeria-sat 1 image was only used for extracting the boundary of the study area. Since the image had already been geometrically corrected, it was thus used as the base map on which all other maps were georeferenced. Georeferencing means to define objects relative to one another. The United States satellite images (Landsat 5 –Thematic Mapper and Landsat 7 – Enhanced Thematic Mapper) finally used in this study were obtained from the Global Land Cover Facility, (2005), (http://glfc.umias.umd.edu/index.shtml). It consisted of one scene from the Worldwide Reference System (WRS-2) of path 189 and row 056 as presented in Table 4.3 and Appendix A.1.

Table 4.3: Satellite data used for image classification

Flight date	Type of satellite image	Bands used	Spatial resolution (m)
21 December 1987	Landsat – 5 TM	1, 2, 3, 4, 5, & 7	30
28 December 2002	Landsat – 7 ETM+	1, 2, 3, 4, 5, & 7	30

4.2.2 Field data

To augment the preliminary data already obtained, four trips were made during the period of research to Nigeria, as against the two that were initially proposed. Due to the multi-disciplinary nature of this research in was not possible to gather all the necessary data in two trips as anticipated during the early stage of the research. Thus, the first trip that was carried out early in the programme (June 2005) was to obtain existing information as outlined in section 4.2.1. The other trips were field surveys to augment already existing information. The first field survey was to obtain environmental data such as, groundtruth (training and testing) data for land cover classification and accuracy assessment of satellite image using Global Positioning System (GPS) from the different landcover classes. This entailed site visits to sample the major land cover types. Built-up/exposed areas, water and cultivated landcover classes were easily sampled. There was difficulty sampling forest and mangroves due to their inaccessibility. Sampling was partially achieved by sampling close to roads and footpaths.

The second was executed mainly to obtain soil and water samples from contaminated sites. In order to locate and access to oil spill sites, the researcher had to engage the services of consultants that have been authorized to operate within the sampled areas. This was necessary has host community members where projects are located are usually hostile to visitors due to the sensitive nature of the causes of oil related issues in the region. It is normally perceived by host community where spill sites are located, that anyone interested in those sites must be those who have been hired by the government or oil companies to further deprive them of their natural resources.

The last field survey was executed in order to collect socio-economic information through questionnaire survey. The questionnaire survey was left to the last stage of the research because of the time it took to arrange the meetings with host community members. It took more that year before approval was given. Even after such approvals have been given, due to the volatile nature of the region, the researcher still had to engage the services of individuals from host communities to gain access to the leaders of such communities.

Stakeholders (actors) and experts from oil and environmental related organisations, lecturers/students and inhabitants of host communities participated in the questionnaire survey.

4.2.2.1 Environmental data

Environmental data were mainly obtained by GPS groundtruthing and soil and water sampling. These were executed by the researcher while other relevant data were sourced for organisations. Table 4.4 summarises the environmental data used.

Table 4.4: Environmental data and sources

Main criteria	Sub-criteria	Unit	Data link to other chapters/sources
Environmental	Effect on groundwater quality/quantity recharge	Index	Chapters 7
	Soil contamination	mg/kg	Field survey
	Impact on vegetation	Index	Field survey
	Characteristics of hydrocarbon spill	-	Reports
	Land cover land use change	%	Chapter 5
	Degradation of surface water quality	Index	Chapter 6

GPS groundtruth data collection

Although geometric correction of the images was already conducted producing positionally accurate orthorectified satellite images having root mean square (RMS) geodetic accuracy of better than 50m (Tucker et al., 2004), it was still necessary to geometrically register the images to each other in order to compare the datasets. Therefore, image registration or geocoding (i.e. converting georeferenced information into digital form) is essential for comparing spatially corrected maps of land cover changes through time. Image registration is the process of an actual geometric transformation of a 'slave' image to the geometry of a 'master' image or map product (Ehlers, 1997). A total of 55 ground control points consisting mainly of road intersections obtained using Geographic Positioning System (GPS) (LOWRANCE, version 2005) were used to register the 2002 ETM+ image. The field survey was carried out in December 2005 so as to tally with the phenological period the satellite images were acquired, thus reducing error caused by seasonal variation.

Soil and water sampling

To supplement data collected from different laboratories as mentioned in section 4.2.1, water, soil and sediments were collected in 2007 for analysis (refer to Appendix B.2 for more details). Water samples were taken from rivers, hand dug wells and boreholes while sediment samples were collected from sides and bottom of rivers. Triplicate samples were taken from each sampling location and were later transported to the laboratory for analysis. One triplicate sample was collected at its natural pH, in 2 litre polyethylene bottles after rinsing several times with water from the point of collection for chemical and hydrocarbon analysis. The second sample used for the analysis of oil and grease was collected in 1 litre dark coloured glass bottle and immediately acidified with sulphuric acid. The third set of samples was collected in 100 ml polyethylene bottles and preserved with nitric acid for heavy metal analysis. Acidification serves to halt biological activity in the sample. Samples were transferred to the laboratory in coolers containing ice so as to reduce the degradation of samples before analysis.

Soil samples were collected randomly at 0-15cm and 15-30cm depths from sites known to have experienced oil spills in the recent past using a hand-dug auger. Samples for chemical and heavy metal analysis were collected in labelled polyethylene bags while those for hydrocarbon analysis were preserved in aluminium foil. With the exception of soil and sediment samples for hydrocarbon determination, the rest of the samples were air-dried in trays placed in clean well ventilated environment and adequately spaced to avoid contamination.

4.2.2.2 Social and economic data

It became necessary to collect socio-economic information as important socio-economic information required in this research was unavailable. This was achieved through questionnaire survey. The sets of questionnaire were prepared carefully taking into consideration input from experts and stakeholders. The initial questionnaire was sampled by these groups to ensure that the questions were well understood and meaningful within the context of the research. Assistance in the preparation questionnaires also was obtained from experts in the social and economic fields.

It is usually impracticable and not cost-effective to actually interview hundreds or thousands of people, unless a full, formal census is taken. Therefore it is necessary to operate with samples, which allow one to work with a small, representative, number of people, and from them infer results about the whole population. One way of choosing stakeholders is for them to be selected based on a demographic stratification of the population that will be affected by the decision (Proctor and Qureshi, 2005). However, this is an extremely expensive process and it is very rare to see such a selection procedure carried out in multi-criteria analysis. The choice of stakeholders can be made using a random sample or a stratified random sample of this relevant population. Needless to say, the information thus gathered is subject to many constraints and assumptions, and is valid only within certain limits, but nevertheless the Theory of Sampling, which lies in the field of Statistics, is a proven tool and used very frequently (Munier, 2004).

Sampling frame

A starting point in designing a sampling frame is to have a comprehensive list of members of the population. There was difficulty in designing a sampling frame for the execution of the questionnaire survey. This was mainly due to the absence of a database and the problem of accessibility to prospective participants both for eliciting weights and scores. In order to obtain expert opinion of assignment of weights to selected criteria, participants were drawn from potential users of the framework. These included oil companies (operators), government organisations (developers and regulators). Lecturers from higher institutions in the field of environment were also included in order to obtain comparative information

Expert opinion can be considered a very important tool, as it provides flexibility without requiring detailed information or data for the problem under consideration. This process is performed by using experience and theoretical knowledge of the expert (Ercanoglu et al., 2006). A description of participants considered for expert opinion is presented in Table 4.5.

Table 4.5: Participants for expert opinion for assignment of weights

Type of expert	Organisation	Number Rating method	Pairwise method
Regulator	Department of Petroleum Resources	8	4
Operator	Oil companies	7	3
Planner/Developer	Federal Ministry of Environment	4	3
Lecturer (Geologist)	University	8	-
Lecturer (Microbiologist)	University	4	-
Lecturer (Chemist)	University	5	-
Total		**36**	**10**

Thirty-six experts were involved in using the rating method (section 3.4.3.1). This method was selected due to its simplicity although lacking in theoretical foundation. In the absence of empirical data to validate local/expert opinions, the pairwise method was used. The framework is expected to be used by end users in government (e.g. Department of Petroleum Resources, Federal Ministry of Environment) and private organisation (e.g. oil companies), therefore 10 experts were approached for validation of weights using the pairwise comparison method. Although this method was theoretically sound, it took a longer period for the questionnaire to be administered and the researcher had to explain in detail the steps involved in using this method.

The fundamental unit of social organization is the household, where individuals produce and share resources. Any actions that destabilize the household are likely to meet with considerable resistance; therefore the second group of stakeholders were taken from the communities who are directly affected by oil activities Table 4.6). Out of the 25 Local Government Areas in the study area, 20 were sampled

Table 4.6: Stakeholders (community members) for assignment of scores

SN	Community	Number participated
1	Aniocha North	7
2	Aniocha South	3
3	Burutu	3
4	Ethiope East	31
5	Ethiope West	4
6	Ika North-East	7
7	Ika South	4
8	Isoko North	5
9	Isoko South	2
10	Ndokwa East	1
11	Ndokwa West	3
12	Okpe	5
13	Oshimili North	4
14	Udu	4
15	Ughelli North	4
16	Ughelli South	6
17	Ukwani	2
18	Uvwie	2
19	Warri South-West	2
20	Warri South	1
	Total	**100**

A total of 100 participants were involved in the eliciting of scores for selected criteria. These set of participants are expected to benefit from the developed framework in terms of the decision outcome. The turbulent nature of the region made it unsafe for the researcher to survey most of the communities in the region. A way out was to train the students from the Delta State University, Abraka on how to complete the questionnaire for dissemination to their respective communities. This was decided against as there was no guarantee that the students will not fill the questionnaire themselves and some questionnaire may also not be returned. The researcher therefore decided to involve the students directly. The high number of participants recorded for Ethiope East as presented in Table 4.4, was as a result of the questionnaire survey was carried out at the Delta State University which is located within the community.

Design of questionnaire

The questionnaires were designed such that they were not too short because in that case the answers will be very constrained. It cannot be very long because people get tired or frustrated with long questionnaires and then give any answer just to get rid of the interviewer. The questionnaire, within its limitations, has to have a broad scope to cover the different aspects which are of interest. Also important is to have an equilibrated sample, which includes a cross-section of population with diverse educational and social levels, as well as with different economic means (Munier, 2004). This was achieved in the host community visited by consultation with the leader of the community who then convened as meeting with subjects.

Two major sets of questionnaire were disseminated to obtain social and economic information for prioritization of contaminated sites. The first questionnaire set was used to obtain scores from host community members (i.e. those directly affected by the decision outcome) as shown in Table 4.7 and Appendix C.4. Due to the diverse educational level of members of community members, a scale of 1 – 3 was chosen. Where 1 = worst, 2 = moderate and 3 = best as it applies to their community/Local

Government Area (LGA). An odd numbered scale interval is normally preferred as it has got a mid-point.

Table 4.7: Social and economic criteria for prioritizing contaminates sites

Criteria	Sub-criteria
Social	Dislocation of persons
	Health impact
	Aesthetic effect
	Effect on cultural resources
	Psychological attitude resulting from spill
	Communal conflict
Economic	Type of income affected
	Magnitude of economic loss
	Effect on sustainable income
	Effect on property value
	Intensity of economic activity around spill

The second set of questionnaire was used to elicit relative importance (weights) of selected criteria and sub-criteria from participants referred to as 'experts' (lecturers and oil sector officials). Since the experts were made up mainly graduates, a 5-point weighting system, where 1 = least important and 5 = most important was applied for deducing the relative importance of selected criteria.

Socio-economic information for the estimation of adaptive capacity index for human vulnerability assessment was obtained through questionnaire survey using selected criteria listed in Table 4.8.

Table 4.8: Socio-economic criteria for estimation of adaptive capacity index

Criteria
Wealth creation and Employment
Improved maternal health
Universal primary education
Poverty and hunger reduction
Youth/gender issue
Global partnership for development
Reduction in infant mortality
Combating common diseases
Shelter and food security
Power and energy
Mass transportation
Ensure environmental sustainability

The selected criteria were obtained from a combination of the UN Millennium Development Goals and the Federal Government of Nigeria seven point agenda as discussed in section 3.5.1.1.

4.3 Spatial and non-spatial database

Database management systems are responsible for storage and management of large amount of data. Two types of database were used in the storage and management of information - spatial and non-spatial.

To develop the required spatial database two software packages were utilized – the Multispec and Integrated Land and Water Information Systems (ILWIS). Multispec is a freeware developed by the Purdue University, USA while ILWIS was developed by ITC, The Netherlands. At the commencement of this research work there were no funds available for the purchase of commercially available software, therefore share/freeware copies were sourced for on the internet. The drawback of Multispec (freeware) was that it does not have a GIS component for further spatial analysis. The ILWIS software (shareware on purchase in 2005, but now freeware) on the other hand possesses both the capability of image processing and spatial analysis, and was thus used for further storage and management of spatial information.

Ortho-rectified Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) images of 1987 and 2002 (path/track - 189, and row/frame – 56) were obtained from the University of Maryland's Global Land Cover Facility (GLCF) website. These created the spatial information of land cover types required for this research. Other spatial information included vector data of oil facilities, geology, rivers, and Delta State boundary as displayed in Appendix A.2.1. The vegetation and land cover layer was created by means of a hybrid unsupervised/supervised classification of Landsat TM satellite imagery (refer to section 5.3.2), while the others were obtained in vector format and had to be imported into the GIS from corresponding electronic thematic maps. Other aspects consisted of attribute tables manipulated by relational database management systems, and a spatial component handled by geographical information systems (GIS) ILWIS.

For the non-spatial database, Microsoft Excel and SPSS Statistical packages were used. The statistical package was used for the storage and analysis of physico-chemical data obtained from water, soil and sediment samples. Socio-economic information extracted from questionnaire survey was also managed using SPSS. After weights and scores had been aggregated in SPSS, they were then transferred and stored in Microsoft Excel database, where standardization and normalization of weights were executed. Aggregation of weights and scores by the Weighted Summation Method was achieved using Excel spreadsheet.

4.4 Methodology

It must be noted that the proposed MCDS framework has been contextualized such that it has a wider applicability in other countries and for other natural resources, for instance in coal mining activities.

4.4.1 Participation of stakeholders/experts

After the identification of stakeholders/experts as outlined in section 3.4.2.1, Participants were divided along the two main groups. The first group are those who are potential users of the framework made up of government and private sector officials. Intellectuals in the field of environment were also included in this group. The group was to provide expert opinion for assigning weights (relative importance) to the different criteria.

The second group are those who are affected by the decision outcome and for the purpose of this study, the local residents in host communities were projects/industries are located were solely for the purpose of obtaining information on the scoring (rating) of selected criteria.

Scores for criteria obtained from students from host communities although residing away from these communities. The scores obtained were tested against students who reside in host communities. Non-parametric statistical analysis was applied in order to check for consistency between community members living within and outside host communities as discussed in section 3.6.2.2 and 7.4.2.

Due to the subjective nature of information obtained from questionnaire survey for MCA, it was necessary to carry out sensitivity analysis as discussed in section 4.5 to test the robustness of the results obtained.

4.4.2 Method of questionnaire survey

There are a variety of survey methods such as by mail, telephone and recently through e-mail. These options were not considered due to lack of facilities for their execution in the Niger Delta. The researcher opted for interview questionnaire survey so as to be present during the administration of the questionnaire. This helped to tackle problems that arose in the interpretation of information contained in the questionnaire. Questionnaire survey has the advantage of minimizing facilitator and participant bias, as participants are expected to complete their questionnaires on individual basis.

4.4.3 Structure of MCDS framework

One of the first problems faced by any research of this nature is defining a common framework for the MCDS framework, upon which to build the decision-making steps (Giupponi et al., 2004). One widely applied general framework used for the selection of criteria for decision making is the Driving Forces-Pressure-State-Impact-Response (DPSIR) framework, as discussed in section 3.3.1. The following sequence of interactions has been followed by the framework

- Socio-economic drivers lead to environmental pressures. (Any phenomenon that is known to alter the state of the natural environment is referred to as a driver).
- Environmental pressures lead to changes in environmental state

- Changes in environmental state are reflected in environmental and socio-economic impacts; and
- Stakeholder gain/losses from impacts lead to policy responses (Office of Science and Technology, 2003).

Figure 4.1 provides at a glance, a description of how this research adapted the DPSIR general framework. Although the DPSIR is a generic framework for the selection of indicators, the different phases were designed to make it applicable to this research needs as explained in the following subsections.

4.4.3.1 Intelligence phase

The intelligence phase begins with problem definition. In the case of this research, the overall objective was to prioritize contaminated sites. There were other intermediate steps such as landscape alteration assessment, soil and water pollution and environmental vulnerability assessment taken for the actualization of the aim. Once the problem has been identified, the DPSIR conceptual framework was used to describe a holistic and multi-dimensional view of this research.

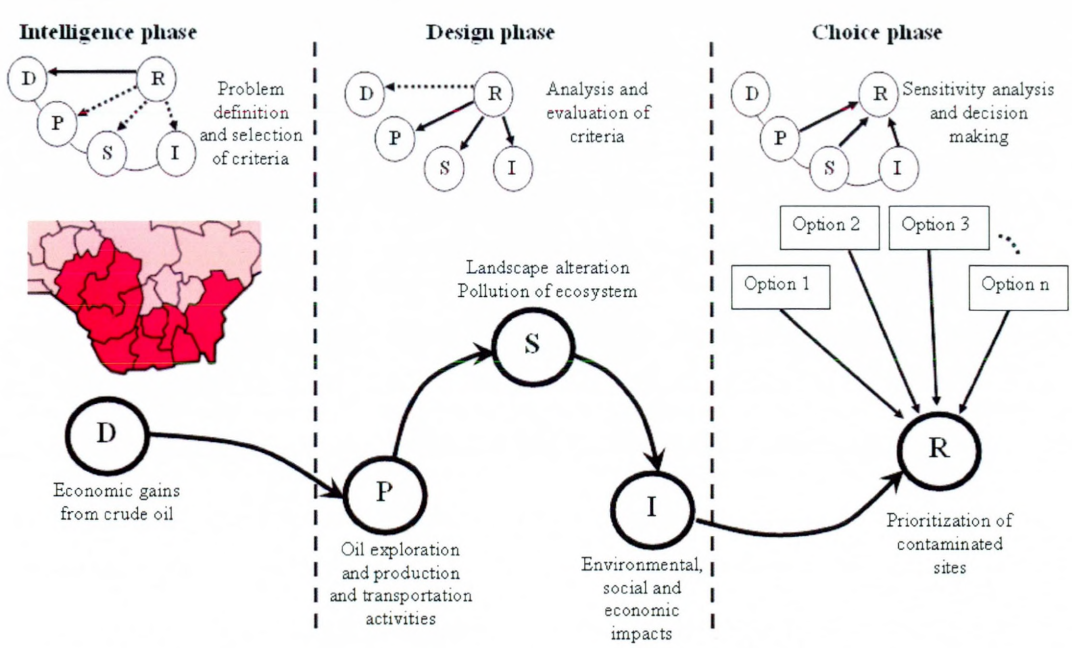


Figure 4.1: DPSIR framework applied to research

In meeting the defined goal or objective, criteria and/or sub-criteria are selected using the structure displayed in Figure 4.2. The various terms - objective, criterion and alternative, as explained in section 3.4.4, were used to structure the process in a hierarchal manner to reduce the complexity of the problem.

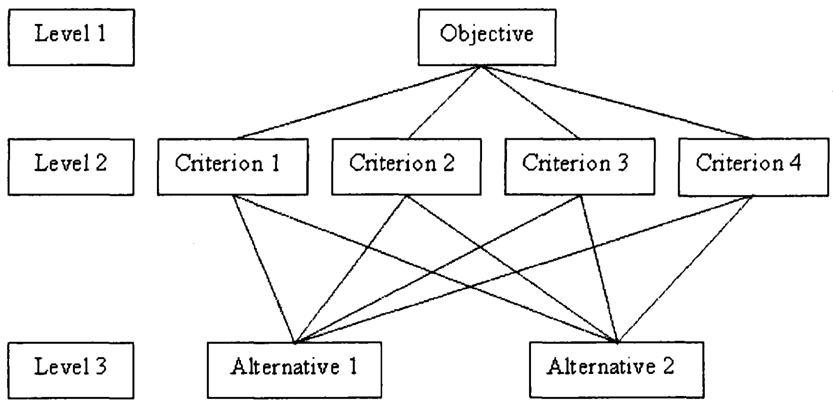


Figure 4.2: Problem with three different hierarchy levels (Qureshi and Harrison, 2003)

4.4.3.2 Design phase

This phase incorporates the identification of alternative options and the selection of the decision criteria. This phase establishes the *pressure* responsible for the defined problem with a view to ascertain the impact of crude oil exploration and production activities on the landscape (Chapter 5), and pathways (Chapter 6), and also the environmental vulnerability of the different targets (Chapter 7). The identification and selection of relevant evaluation criteria for establishing these tasks are an essential component of the design phase. The weighting and scoring, through multi-criteria analysis, take the decision maker to the next phase.

4.4.3.3 Choice phase

The choice phase which involves the ranking or selection of alternatives is discussed in more detail in Chapters 8.

4.4.4 Components of MCDS framework

Figure 4.3 show the main components of the MCDS framework developed in this research. It is composed of three main parts – Database storage and management (DSM), Computer Systems Applications (CSA) and Multi Criteria Analysis (MCA).

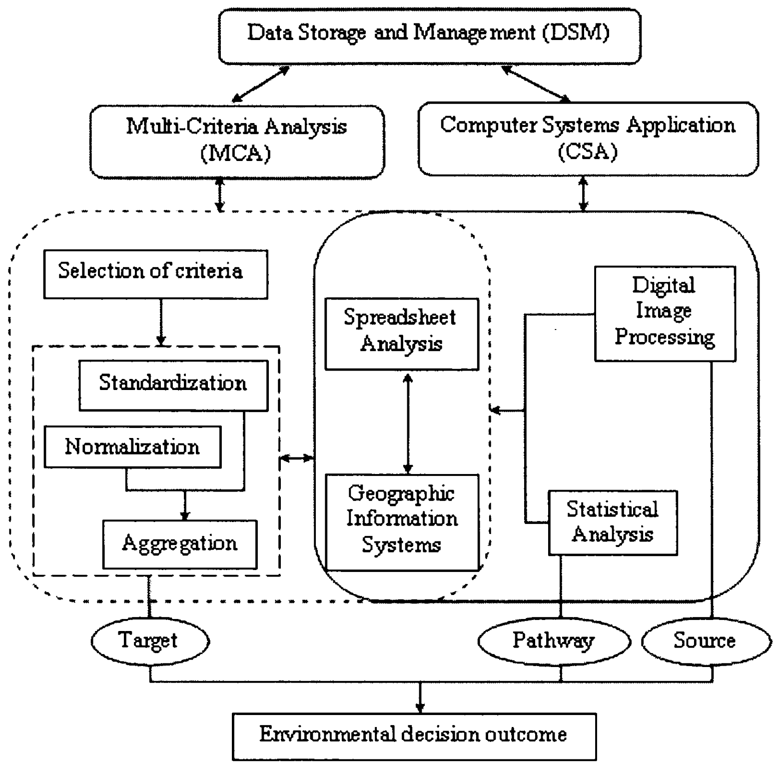


Figure 4.3: Components of MCDS framework

4.4.4.1 Data storage and management

It was essential to create a database for the storage and management of information for environmental impact assessment. This has become more significant with the advanced techniques of obtaining spatial data and rapid developments of personal computers and GIS technology. GIS was the main database used mainly due to its ability to integrate both spatial and non-spatial data. It was augmented by the SPSS (version 15), which was used for the storage of water soil and sediment data. Lastly Microsoft Excel spreadsheet was applied for the standardization and normalization of scores and weights. It was also used for aggregation of weights and scores by the weighted summation method (WSM) as discussed in section 3.4.3.2. The software compatibility of SPSS and Excel was an advantage to this work and made data exchange feasible.

4.4.4.2 Computer systems application

The Literature has substantial discussion of the different methods of integrating external MCA software packages with CSA such as GIS, and a number of different viewpoints exist as discussed in section 3.7.3. Currently, most models adopt a 'loose-couple approach', which adds customer-built programs to a commercial CSA package and uses a spatial GIS for data management and display (Zeng et al., 2001). This research work took a semblance to the 'loose-couple approach' although there were no built-in programs for data exchange. This was unnecessary due to the compatibility of the software packages that were utilized.

Geographic information system (GIS)

GIS is often recognized 'as a decision support system involving the integration of spatially referenced data in a problem solving environment' (Cowen, 1988, Denzer, 2002). GIS provides the capability of storing, managing and retrieving large amounts of spatially related data. A GIS based framework supports the understanding of complex spatial relationships among variables and can support participatory decision-making and problem-solving activities (Killpack et al., 2000).

Digital image processing

In the vulnerability assessment and prioritization of contaminated sites, it is essential to possess recent landscape data. An exhaustive investigation revealed the absence of spatial information in the appropriate digital format. It then necessitated the utilization of satellite images for the extraction of land cover types. Section 3.2.1 gives a review on digital image processing while Chapter 5 discusses in detail the methodology applied in this research.

Spreadsheet and statistical analyses

SPSS Statistical package and Microsoft Excel were used to calculate the average scores and relative importance (weights) of the criteria and sub-criteria. While spatial aggregation was executed using the ILWIS software package (E.C. Inc. 1995). The Microsoft Excel and SPSS database management systems (DBMS) were selected for the creation and calculation of non-spatial database, due to their ease of use and they are less expensive when compared to other DBMS.

Both univariate and multivariate statistical methods were applied to obtain the nature and extent of pollution of soil and water (surface and groundwater) within spill sites. This is discussed in detail in section 3.6.2 and Chapter 6.

4.4.4.3 Multi-criteria analysis (MCA)

MCA is a range of evaluation methods that attempts to aid decision makers in situations when judgment depends on more than one criterion. It encompasses a rich and diverse set of techniques that are widely used in fields from economic analysis to environmental impact assessment (Villa et al., 2002). It has the advantage over other decision methods as it not only incorporates numerical data but also experience from a wide range of stakeholders.

MCA provides a technically sound decision tool for management of contaminated areas where stakeholder participation is of crucial concern and criteria such as economics, environmental and social impacts cannot be condensed into simple monetary expressions. A summary of the commonly used MCA is provided by a number of authors (DTLR, 2001, Hunjak, 1997, Pohekar and Ramachandran, 2004, Romero and Rehman, 1987).

The two main tools used for MCA as applied in this study are the Microsoft Excel spreadsheet for discrete MCA and GIS for spatial MCA. MCA was used in standardizing, normalizing and aggregating of the established criteria. The need for standardization became necessary where scores with different measurement scales needed to be compared. MCA was performed using Weighted Linear Combination (WLC) and Boolean methods. The WLC technique is a commonly used GIS - based decision rule for deriving composite values where there are tradeoffs among indicators and criteria (Malczewski, 1999). The primary reason for its popularity is that the method is easy to implement within the GIS environment, using map algebra operations and cartographic modelling (Tomlin, 1990). For a detailed review of WLC, refer to Malczewski (2000). Boolean on the other hand considers all layers by using logical operators that do not allow for trade-off. The evaluation of contaminated areas was based on the assignment of weights and ranks. The direct weighting method was applied for weighting the selected criteria. These indicators/criteria were integrated into the Excel spreadsheet and GIS platform through the use of MCA to generate more robust and accurate decision. The processes involved in MCA are standardization of criterion score, normalization of criterion weight and aggregation (ranking) of weights and scores (refer to Chapters 7 and 8).

Standardization of criteria

Some of the assessment criteria were measured on different measurement scales; therefore they had to be standardized to the same scale. For instance, the Potential Impact Assessment (PIA) and Adaptive Capacity (AC) criteria (see section 7.2.5.1), were all standardized on a scale of 0 - 1. The standardization procedure gives relative values. A value of 0 could indicate the best or worst outcome (i.e. the area has the highest or lowest negative impact) for each criterion, depending on what is being assessed. The most frequently used formula for standardizing the raw data is to divide each raw score by the maximum value for a given criterion (Malczewski, 1999). Therefore, the rank values of the classes were standardized according to the relative distance between the origin and the maximum rank value, using the following formula:

$$x = x_i / x_i^{\max} \tag{4.1}$$

where x is the standardized score value for the ith class, x_i is the raw score and $x_i^{\max}$ is the maximum score value.

Normalization of weights

The traditional 5 point interval scale of 1 to 5 where 1 denotes least important and 5 the most important was used in the assignment of weights. In order for the weight values to be combined, the process of normalization was carried out by dividing each weight by the sum of the weights such that their total sum equals unity. A normalization of weights was accomplished using the formula (also referred to as the direct method)

$$z = y_i \Big/ \sum_{i=1}^{n} y_i \tag{4.2}$$

Where z is the normalized weight value for the ith class, y_i is the raw weight.

Aggregation of alternatives

After the completion of standardization and normalization procedures for criteria and sub-criteria, they need to be evaluated. The weighted summation method (WSM)was chosen due to its simplicity and because it also provides a complete ranking of alternatives (Balasubramaniam et al., 2007). The equation for the calculation of weighted summation for discrete data is

$$S_1 = \sum (w_j x_{ji}) \tag{4.3}$$

WSM is based on the concept of a weighted average and involves the simple process of multiplying a score against a criterion x_{ji} by the weight of that criterion w_j, before finding the sum of the weighted scores.

Due to the spatial nature of some sub-criteria, aggregation was achieved using Equation 4.4.

$$S_2 = \sum_{i=1}^{n} w_i x_i \prod_{j=1}^{m} c_j \tag{4.4}$$

where w_i is the weight of factor i, x_i is the criterion score of factor i, n is the number of factors and c_j is the criterion score (1 or 0) of constraint j and m is the number of constraints.

Constraints are binding criteria where no compensation is allowed while factors allow for compensation. Poor performance of one criterion can be compensated by good performance of another in factor. Furthermore, factors can either be a benefit (the higher the value, the better) or a cost (the higher the value the worse).

4.5 Sensitivity Analysis

The major problem of using MCDA methods in decision-making is the lack of justification and objectives, therefore results inevitably are associated with some form of uncertainty (Chen et al., 2001). These could be caused by four components: criterion uncertainty, assessment uncertainty, priority uncertainty and method uncertainty (Voogd, 1983). According to Sharifi (1999), criterion uncertainty is dependent on the choice of evaluation criteria. This can be reduced by the involvement of experts in selecting criteria that can fulfil the minimum requirement, realistic and are acceptable to all stakeholders. Assessment uncertainty relates to the ambiguity in each criterion score, i.e. the degree to which an option meets a criterion. One of the ways of dealing with assessment uncertainty is by sensitivity analysis. Priority uncertainty concerns itself with the criteria relative importance (weights) and scores particularly when weights are quantitatively assessed. Priority uncertainty can also be addressed by sensitivity analysis. Finally, method analysis deals with the reliability of the evaluation method. The use of two evaluation methods WSM and AHP helped to reduce uncertainty based on method of analysis.

4.6 Summary

The major data sets required as input for the MCDS framework have been enumerated. Preliminary data was augmented by data obtained during field survey.

These were all stored in spatial and non-spatial databases. The method of survey was highly dependent on the type of sample population and information required.

The structure and major components of the MCDS framework developed by the researcher was multidisciplinary, thus requiring different tools as well as input from experts in related fields of environment and natural resources. The major advantage of incorporating MCA techniques into GIS-based procedures is that the decision-makers can insert value judgments (their preferences with respect to evaluation criteria and/or alternatives) into GIS-based decision-making procedures, and receive feedback on their implications for policy evaluation (Malczewski, 2006).

MCA can be used to measure and map a range of potentially competing representative values impacted by establishing stakeholder preferences while GIS can be applied in mapping and further to spatially identify which areas required priority attention.

Chapter 5 : Impact Assessment of Landscape using a Remote Sensing Methodology[1]

5.1 Introduction

This chapter deals with a methodology for rapid, cost effective and efficient land cover classification and change detection technique to monitor the geophysical dynamics in the region. With the continuous conflict over the impact of oil activities in the area, this study was conducted to develop a systematic methodology for detecting changes of landcover (LC) types obtained from satellite data, which are important factors to consider in the design of an environmental decision-support framework for prioritising contaminated areas (refer to Chapter 8).

Regular and up-to-date information on landscape change is required for planning and land use management. Consequently, the need has arisen to develop a reliable methodology for monitoring the ever changing landscape of the Niger Delta region. This chapter therefore, addresses the use of a hybrid classification method to detect changes that have occurred in the study area between 1987 and 2002.

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[1] Major outcomes of this work discussed in Chapter 5 were presented at the following conferences
Omo-Irabor O.O. and Oduyemi, K. 2007. A Hybrid Image Classification approach for the Systematic analysis of Land cover (LC) Changes in the Niger Delta region. A paper presented at the *5th International Symposium on Spatial Data Quality (ISSDQ)*, 13-15 June, 2007, ITC, Enschede, Netherlands

Omo-Irabor O.O. and Oduyemi, K. 2006. A comparative Study of Classification Methods for monitoring Landuse/Land cover changes using remote sensing and GIS Techniques. A paper presented at *the 6th International Conference on Earth Observation and Geoinformation Sciences in Support of Africa's Development*, 30 October-2 November, 2006, Cairo, Egypt, 2006.

5.2 Land Cover Classification System

The initial step in performing image classification is the selection of a land cover (LC) classification system. Within the context of this study LC as defined by Lambin et al. (2000), refers to the attributes of a part of the Earth's land surface and immediate subsurface, including biota, soil, topography, surface and groundwater, and human structures. LC is a fundamental variable that impacts on and links many parts of the human and geophysical environment and LC change is regarded as one of the most important variable affecting ecological systems globally. Due to the complex LC patterns existing in the study area and the occasionally indistinguishable relationship between LC and spectral signals, this study introduces techniques based on information obtained from satellite images. The modified LC classification systems derived from the Anderson Classification System and Forestry Management and Evaluation Co-ordinating Unit (FORMECU) was applied in this study. Six LC classes as shown in Figure 5.1 and Appendix A.1 were selected, indicating the major distinct classes in the area. These included; built-up/exposed areas, cultivated land, mangrove (short and tall), natural forest, palm forest and water.

Figure 5.1: **Oblique view of major landcover classes**

5.3 Methods

The methodology used for land cover classification and detecting changes in the landscape include, pre-processing, image classification, accuracy assessment, and post-classification change detection as discussed in section 3.6.1.

5.3.1 Pre-processing

Pre-processing of satellite data is essential, in order to minimise effects that obscure links between the image data and the biophysical phenomena being studied. The aim is to eliminate errors associated with data acquisition including sensor effects, atmospheric and illumination effects and misregistration. The procedure for pre-processing of satellite data has been enumerated in section 3.6.1.1. The actual steps followed in this research are given below.

5.3.1.1 Geometric rectification

The images acquired were already partially rectified (see section 3.6.1), therefore an affine transformation was used to rectify the 1987 TM image to the 2002 ETM+ using the UTM map projection (Zone 32), World Geodetic System 1984 datum (WGS 84) co-ordinate system. As the study area has relatively even terrain relief, only the first degree polynomial equation was required for image transformation. The nearest neighbour re-sampling method was used to avoid altering the original pixel values of the image data thus preserving the radiometry and spectral information of the images. The images were re-sampled to 28.5 m. The resultant root mean square error (RMSE) was about 0.5 pixels, indicating a high quality registration. According to Symeonakis et al. (2006), absolute pixel errors of more than one pixel can be a cause of concern in multi-temporal studies.

5.3.1.2 Elimination of clouds

Constant cloud cover is a major problem hindering the use of remote sensing data in tropical regions. In order to improve the misclassification of land cover classes, clouds needed to be eliminated from the image. The problems posed by their presence are two fold. Firstly, cloud cover increases the land cover classes that have high spectral reflectance e.g. sediments and concrete structures. Secondly, cloud cover reduces the land cover classes that they overlay on the image. Close inspection of the pixel values of the different bands showed that band 4 (spectral range of 0.76 -0.90 μm) could be used to differentiate between cloud and other land cover classes effectively. The threshold digital value used for the differentiation of cloud with other high reflectance features such as sediments was 95. This value gave the best spectral separation between cloud cover and other high reflectance features such as sediments.

Although this procedure effectively removed over 90% of clouds, the problem of knowing the landcover type to replace the clouds with posed a problem. This was tackled by using conditional 'IF' statements to fill the spaces with landcover types in close proximity to the previously occupied cloud pixels (Appendix A.4).

5.3.2 Image Classification

Image classification involved the steps outlined as in section 5.3.2.1.

5.3.2.1 Image band selection

The first step required the selection of band for colour composite. It was important that selected bands had low correlation to reduce the problem arising from linearity among images. Another area of interest was to select bands with spectral variation. Based on correlation coefficient results shown in Tables 5.2 and 5.3, bands 5, 4 and 2 were used for the three-band combination colour composite.

Table 5.1: **Correlation matrix for Landsat 1987 bands**

Correlation matrix	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Band 1	1.000					
Band 2	0.801	1.000				
Band 3	0.634	0.851	1.000			
Band 4	-0.393	-0.332	-0.360	1.000		
Band 5	-0.278	0.037	0.272	0.504	1.000	
Band 7	-0.059	0.275	0.551	0.219	0.912	1.000

Table 5.2: **Correlation matrix for Landsat 2002 bands**

Correlation matrix	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Band 1	1.000					
Band 2	0.928	1.000				
Band 3	0.802	0.913	1.000			
Band 4	0.021	0.089	0.037	1.000		
Band 5	0.162	0.320	0.517	0.509	1.000	
Band 7	0.273	0.436	0.671	0.235	0.921	1.000

5.3.2.2 Unsupervised classification

The Iterative Self-Organising Data Analysis Technique (ISODATA) clustering algorithm was applied for the initial unsupervised classification. It is a modification of k-means clustering algorithm (Jensen, 2005). ISODATA algorithm makes use of the minimum spectral distance formula to form clusters. The clustering procedure as outlined in section 3.6.1.2.1 was applied. The initial number of clusters used for classification was set at the default value of 10.

The other required parameters included the maximum percentage of pixels whose class values were allowed to remain unchanged between iterations and the minimum cluster size. 99% and 7 were chosen for convergence value and minimum cluster size respectively. A value of 100 was selected as the threshold convergence value. This implies that the system is forced to assign every pixel in the image to one of the clusters. A value of less than 100 results in some pixels not being assigned to clusters (Multispec., 2001). Although the default number of 10 clusters was selected, the classification result which arranges and assigns clusters in order of descending level of brightness produced 7 clusters. Figure 5.2 shows the resulting colour assigned to each cluster by default. This default colour is meaningless and does not bear any relationship with the true colour of the landcover it represents.

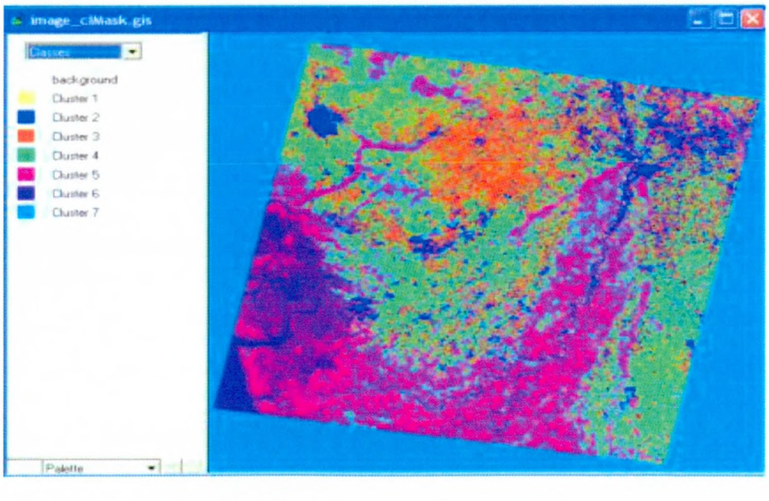


Figure 5.2: Unsupervised classification producing seven clusters

Colours were assigned to the different clusters with the aid of digital vegetation, land use maps and ground truth data. Figure 5.3 displays the true colour scheme which closely resembles those of the features being represented.

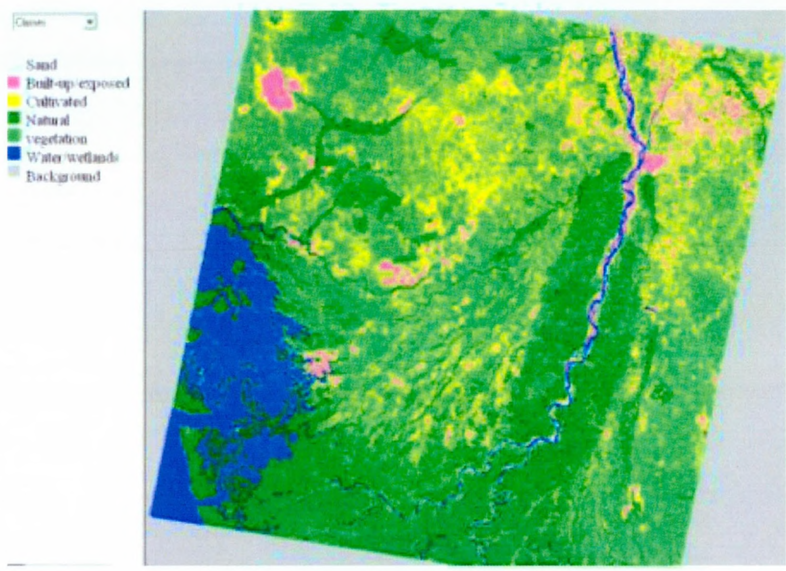
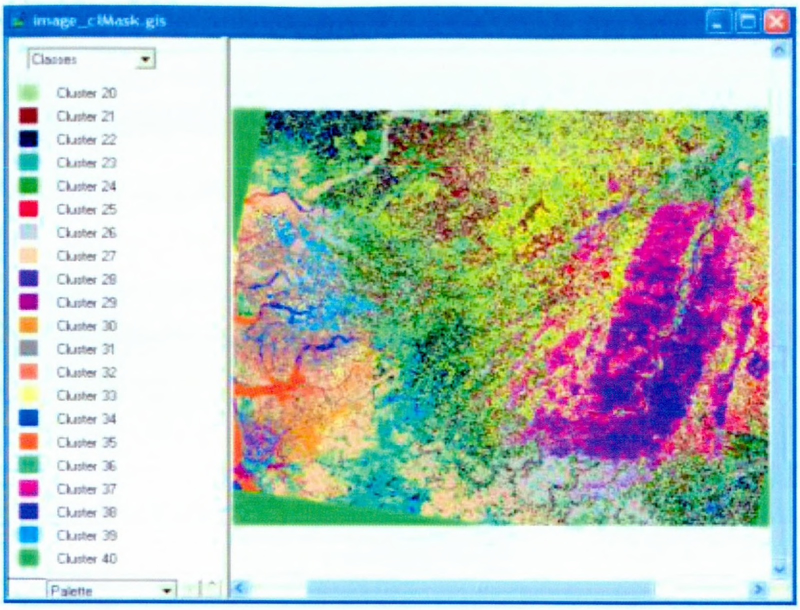
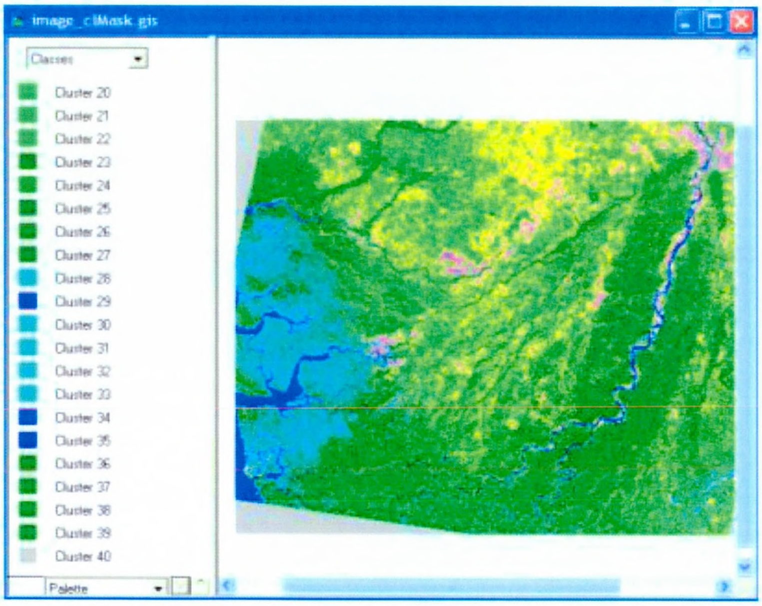


Figure 5.3: Colour assignment to clusters with the aid of groundtruth data

An increase in the number of clusters was necessary as there was difficulty in discriminating among water bodies, natural vegetation and mangrove. After a number of iterations, the final number of clusters selected was 40 and are presented in Figures 5.4a & b.



(a)



(b)

Figure 5.4: Unsupervised classification with 40 clusters (a) before assignment of colour by analyst (b) after colour assignment

5.3.2.3 Supervised classification

Maximum likelihood is the most commonly used supervised classification technique, and it is based on the assumption that the training data statistics in each band are normally distributed. Supervised classification began with defining the areas that were to be used as training sites for the different land cover classes. A prior labelling of pixels was then performed on the selected training sites with the aid of results obtained from the unsupervised classification (refer to section 5.3.2.2) and vegetation/landuse maps. A minimum of 15 samples was initially selected for each class. Ideally, the number of pixels selected should be more than 10 times as many pixels as there are bands in the image to be classified (Jensen, 2005). This was made with several training sites, for the more training site selected, the better the results obtained as shown in Figure 5.5.

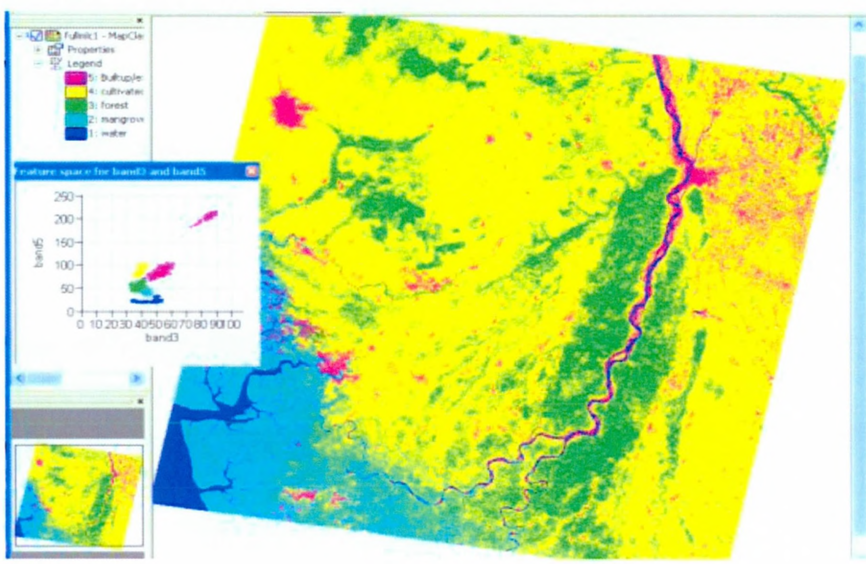


Figure 5.5: Supervised classification of image

5.3.3 Image reclassification

Preliminary examination of the classified images using the two algorithms revealed a wide range of spectral confusion among land cover types. Spectral confusion refers to the fact that several land cover classes have similar spectral response and this poses a major problem of classification inaccuracy (Yang and Lo, 2002). To reduce this problem, close inspection of the classes was executed to highlight major areas of misclassified land cover. This was achieved with the aid of vegetation/land use maps and local knowledge. Most water pixels were initially classified as mangrove even outside the boundaries of the mangrove swamp. Therefore, to improve on the classification of water, mangrove and water clusters in the unsupervised images were all grouped as water. A resultant attribute map was created for water class only. Additionally, an attribute map was made for natural forest clusters as they were well discriminated from other land cover types in the unsupervised classification especially within the Coastal plain sands geologic unit (Appendix A.2.2).

The study area was then sub-divided into 2 main terrain units, whereby the mangrove swamp was separated from the other terrain units. The attribute maps were then incorporated into two supervised classified maps with the aid of conditional statements. Smoothening of the classified images to remove the salt and pepper appearance as shown in Figure 5.6 was achieved using a 3x3 majority filter.

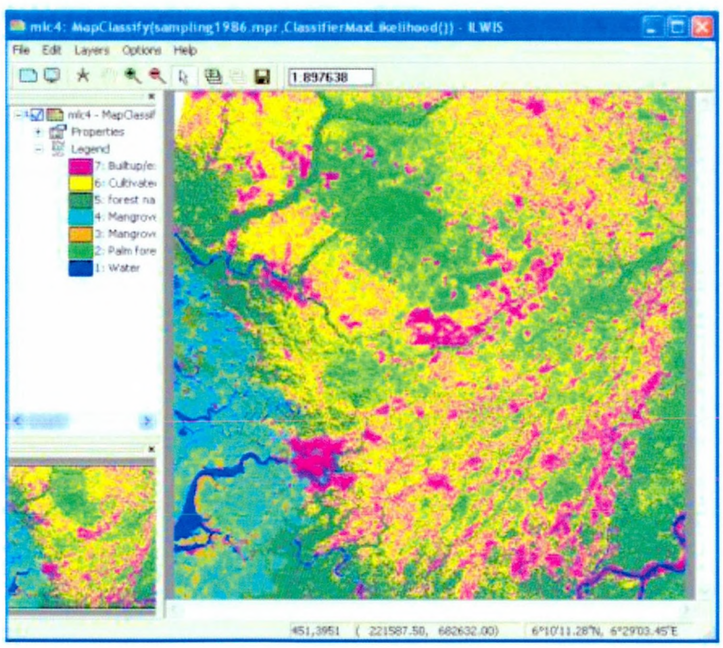


Figure 5.6: Salt and pepper appearance of classified image

The reclassified images are shown in Figure 5.7a & b.

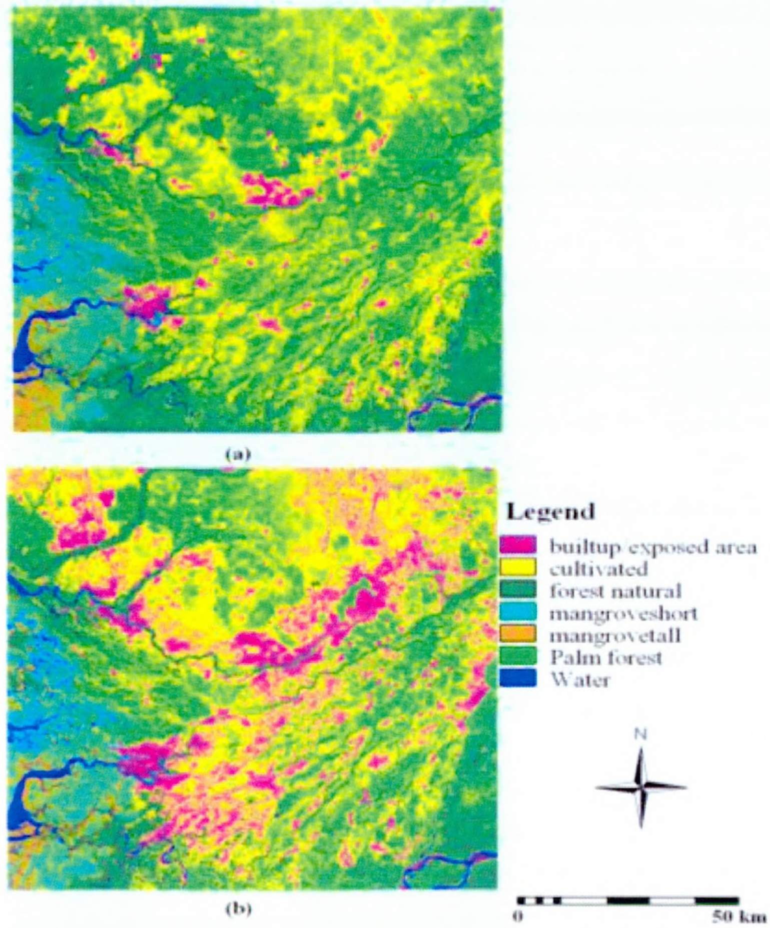


Figure 5.7: **Classified images (a) Landsat TM 1987 (b) Enhanced Thematic Mapper plus (ETM+) 2002**

5.3.3.1 Accuracy assessment of classified images

Classification accuracy is necessary to establish the performance of derived thematic map with ground truth or other reference data set. The confusion matrix is the most frequently used way of expressing classification accuracy. Information in the confusion matrix is evaluated using univariate (e.g. producer's, user's and overall accuracies) (Jensen, 2005). Digital vegetation and land use maps prepared by the Nigerian Forestry Management, Evaluation and Coordinating Unit (FORMECU) and Niger Delta Environmental Survey (NDES) were used for verifying the accuracy of the classified Landsat TM 1987 image. The verification data for the 2002 classification were slightly biased due to the inaccessibility of majority of the region. Sampling was therefore executed close to roads during field visits in 2006 with the aid of GPS.

5.3.4 Change detection analysis

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Successful use of satellite remote sensing for land cover change detection depends upon an adequate understanding of landscape features, imaging systems, and information extraction methodology employed in relation to the aims of analysis (Yang and Lo, 2002). The selection of an appropriate change detection algorithm is essential because it has a direct impact on the type of classification to be performed and whether important change information can be extracted from the image (Jensen, 2005).

Broadly speaking, change detection algorithms can be divided into two groups; those that produce from–to land-cover class information, and those that simply detect the presence or absence of change (Currit, 2005). This research applies the later which involves separately classifying the images and then running a post-classification comparison. Although the accuracy of post-classification methods is dependent on the accuracy of the individual classifications and is subject to error propagation, the classification of each date of imagery builds a historical series that can be more easily updated and used for applications other than change detection (Yuan et al., 2005). Also, this method avoids the problems that arise due to variation in sensor characteristics, atmospheric effects, solar illumination angle sensor view angle and vegetation phenology between dates since each image is independently classified (Chen et al., 2005a).

5.4 Results

The results of the hybrid classification method for the 1987 and 2002 images are shown in Tables 5.3 and 5.4 respectively. The overall accuracy assessment of the 1987 and 2002 images are 83% and 76% respectively. A previous classification carried out by Omo-Irabor and Oduyemi (2006)using unsupervised ISODATA classification method for the study area gave 61% and 69% for 1987 and 2002 respectively. The accuracy assessment values are lower than those obtained by James *et al.* (2007). This could be as a result of the misclassification of palm forests which affected the accuracy assessment of both 1987 and 2002 images. Also the presence of palm trees in all land cover classes in the region, with the exception of water bodies affected the results. The hybrid classification approach developed in this study aided improved separability among built-up/exposed areas, water bodies and natural vegetation land cover classes.

Table 5.3: **Confusion matrix for 1987 image**

Land cover classes	BE	CL	NF	MT	MS	PF	W	Total	User's accuracy (%)
Built-up/exposed areas (BE)	183							183	100
Cultivated land (CL)	9	318				27		354	90
Natural forest (NF)			296			127		423	70
Mangrove (tall) (MT)				99	9		2	110	90
Mangrove (short) (MS)			1		117			118	99
Palm forest (PF)	28	82	7			49		116	30
Water (W)							108	108	100
Total	220	400	304	99	126	203	110	1462	Overall accuracy 83 %
Producer's accuracy (%)	83	80	97	100	93	24	98		

Table 5.4: **Confusion matrix for 2002 image**

Land cover classes	BE	CL	NF	MT	MS	PF	W	Total	User's accuracy (%)
Built-up/exposed areas (BE)	46	0	0	0	0	0	0	46	100
Cultivated land (CL)	0	49	0	0	0	2	0	51	96
Natural forest (NF)	0	3	25	0	0	0	0	28	89
Mangrove (tall) (MT)	2	0	2	14	6	0	0	24	58
Mangrove (short) (MS)	0	0	5	0	17	0	0	22	77
Palm forest (PF)	1	7	22	0	0	11	0	41	27
Water (W)	0	2	0	0	0	0	11	13	85
Total	49	61	54	14	23	13	11	225	Overall accuracy 76%
Producer's accuracy (%)	92	80	48	100	74	85	100		

From Table 5.5, cultivated land occupies more than a third of the total land areas in both years. The mainstay of majority of the rural dwellers in the upland region is farming. Since the post classification accuracy is dependent on the initial accuracies of the classified images, this gives a reduced accuracy of 63.24%. The greatest depletion of land cover occurred in natural forest. An amount of 9.21% equivalent to 1113.00 km^2 of natural forest disappeared within the 15-year period. This result is in line with Osei *et al.* (2006), that forest estate of only about 10 million hectares

(10 percent of total land area of Nigeria) is declining at a rate of 3.5 percent annually. The main factor responsible for this decline can be attributed to logging activities especially in the upland regions. Palm forest comprising mainly of secondary growth, scrub and palm plantations experienced the second largest decline of 7% (853.8 km^2), arising from the demand for cultivated lands. All other classes showed increase in cover change, with built-up/bare areas and cultivated areas increasing by 11% (1282.73 km^2) and 5% (637.9 km^2) respectively. Water bodies increased by 7%,. This can be attributed to the classification of shadow as water bodies in the 2002 image. The increase in short mangrove may be due to the colonization of a wild tree species known as Nypa (Niger Delta Environmental Survey, 1997). This species is difficult to distinguish from mangrove on satellite images as a result of similarity in spectral reflectance.

Table 5.5: **Change of land cover classes between 1987 and 2002**

Land cover classes	1987 image		2002 image		Change	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	(km^2)	(%)
Built-up/exposed areas	459.1	3.80	1741.8	14.42	1282.7	10.62
Cultivated land	4217.3	34.90	4855.2	40.18	637.9	5.28
Natural forest	3462.8	28.66	2349.7	19.45	1113.0	-9.21
Mangrove (tall)	549.3	4.55	471.3	3.90	78.0	-0.65
Mangrove (short)	501.9	4.15	523.1	4.33	21.1	0.17
Palm forest	2621.5	21.70	1767.7	14.63	853.8	-7.07
Water	270.4	2.24	373.5	3.09	103.1	0.85
Total	12082.3	100	12082.3	100		

5.5 Summary

The purpose of the aspect of this research work was to develop a rapid method of producing temporal land cover maps for change detection analysis. This study introduced a novel approach of combining the results from the two (supervised and unsupervised) image classification algorithms. They were combined with knowledge of terrain characteristics, in such a way that only areas that gave acceptable results were combined and used for further analysis. Thus, the problem of spectral confusion was significantly reduced in some land cover types such as water, natural forest and mangrove. This can further be improved by the use of topographic information. While the research was able to obtain freeware topographic data (SRTM) from the US NASA website, the information could not be analysed due the unavailability of software required and time constraint at the time the analysis were executed. Although the performance of this hybrid approach improved discrimination of land cover types especially in the upper section of the study area, the misclassification of palm forests affected the accuracy assessment of both 1987 and 2002 images.

This Chapter also revealed the importance of temporal and spatial remote sensing data and GIS tools in detecting the degradation of the environment from development activities in the region. The depletion of forest and mangrove can be attributed to logging, creation of land for farming and oil activities. While the presence of oil companies in the region has attracted labour thus increasing urbanisation. In the absence of an alternative rapid and cost-effective means of obtaining landscape information for monitoring the constant changes, this systematic approach becomes necessary although it needs to be continuously revised, as other techniques for improving the accuracy of remote sensing data are developed.

Chapter 6 : Physico-chemical characterization of Crude Oil Pathways[2]

6.1 Introduction

With the persistent problems arising from oil activities, the ability to meet soil and water environmental standards in the area of study is proving to be a big challenge. Soil and water quality data are essential criteria for monitoring the general well-being of the environment. Several agencies and organizations such as the US Food and Drug Administration (US FDA), Food and Agriculture Organization (FAO), and the World Health Organization (WHO) provide guidelines on the intake of trace elements by humans (Ikem and Egiebor, 2005). WHO has continued to revise Guidelines for Drinking-water Quality (World Health Organization., 1993, World Health Organization, 2004) and additional guidelines are issued as new substances are evaluated or as new scientific information become available (Twort et al., 2000)

This research utilizes the source-pathway-target approach, where the impact of oil spills on different pathways (soil and water) is the main focus as presented in Figure 6.1. In other to establish the impact, concentrations of elements were compared with existing standards and likewise areas that had not experienced any form of pollution from oil spills.

[2] Aspects of this chapter have been published and presented as:
Omo-Irabor O.O., Olobaniyi S.B., Oduyemi K. & Akunna J. (2008) Surface and ground water quality assessment using multivariate analytical methods - A case study of the Western Niger Delta. *Journal of Physics and Chemistry of the Earth*

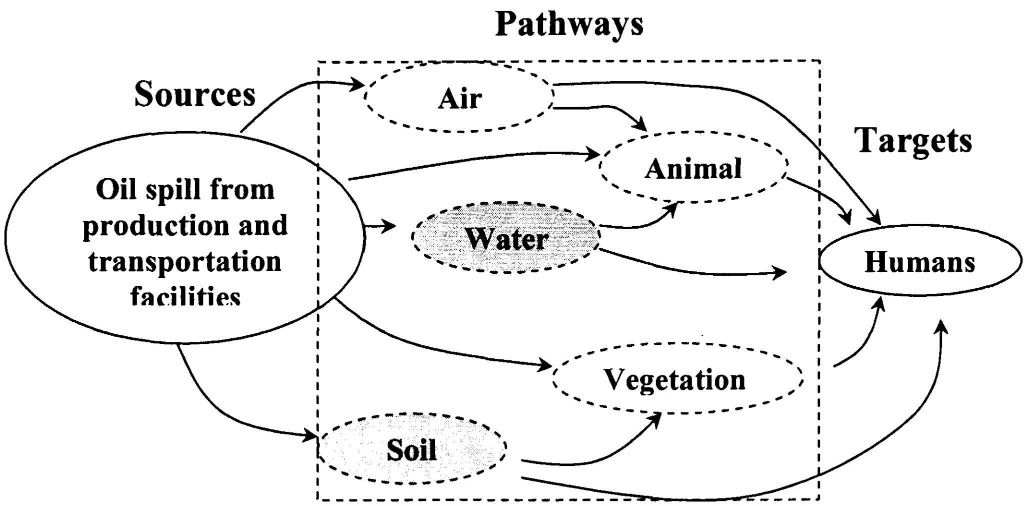


Figure 6.1: Pathways used for environmental impact assessment

This work also introduced a statistical approach in establishing the relationship among pollutants. Multivariate statistical methods such as principal component analysis and factor analysis were used to reduce the redundancy of physico-chemical constituents of surface and groundwater, thereby emphasizing those parameters that are enhanced due to oil spill. The spatial distribution of physico-chemical constituents of surface and groundwater was established using cluster analysis.

Environmental (soil, sediments, water and air) contamination in the form of heavy metals is one of the less obvious impacts that can have very severe consequences (Obiajunwa et al., 2002). This work therefore applies univariate statistics on soil and sediment samples from oil spill sites and 'control' sites to determine baseline level of contamination for utilization in the MCDS framework.

6.2 Laboratory Procedures for Physico-chemical, Heavy Metals and Hydrocarbon Constituents of Soil and Water

Analytical parameters were selected based on extensive study and consultation with experts in the field of analytical chemistry. Based on the outcome, 28 physico-chemical parameters were analyzed, in accordance with recommended methods of analysis (APHA, 1995) and (ASTM., 2001) as displayed in Appendix B.1.

The temperature, pH and electrical conductivity measurements were performed in situ with a mercury-in-glass thermometer, portable Orion Model 290 pH meter and Oakton Model 35607 meter respectively. Values for DO and BOD were obtained using the Winkler's azide method. The major cations and heavy metals were analysed using the atomic absorption spectroscopy (AAS) and flame atomic absorption spectroscopy (FAAS) respectively. The gas chromatograph flame ionized detector (GCFID) was employed in measuring the total petroleum hydrocarbon (TPH) (refer to Appendix B.3). A summary of analytical results for soil and water are presented in Appendix B.4. The standard approach to physico-chemical characterization is to compare measured constituents with established standards/guidelines as shown in Appendix B.5. The incompleteness and inconsistency of these standards for providing threshold values for some parameters brought about the utilization of a statistical approach as discussed in section 6.3.

6.3 Statistical Analysis

Water quality data sets collected from the study area as shown in Figure 6.2 were subjected to multivariate analysis: cluster analysis (CA) and principal component analysis (PCA)/factor analysis (FA). These analyses required a preliminary step of the treatment of data which consisted of the normalization of the raw analytical data, so as to avoid misclassifications due to the different order of magnitude and range of variation of the analytical parameters (Aruga et al., 1995). Multivariate statistical computations were executed using the statistical software package, SPSS 14.0. The multivariate methods utilized have been described in section 3.5.1.

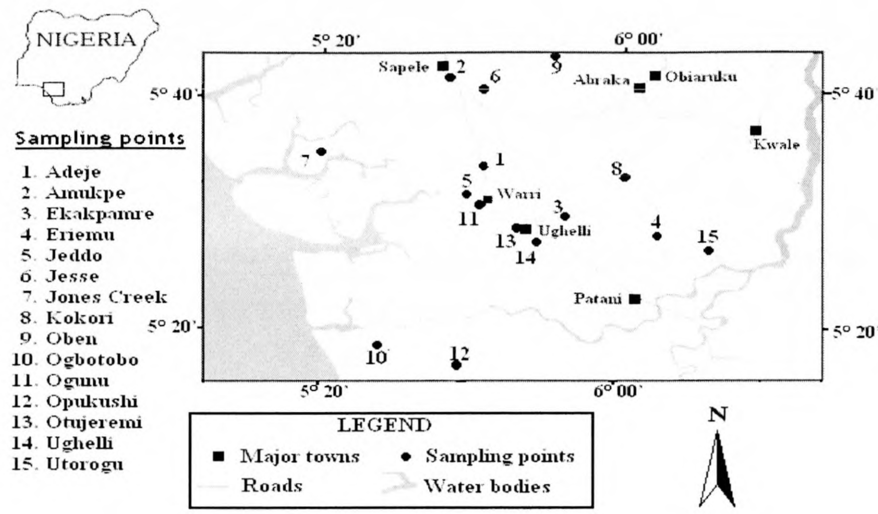


Figure 6.2: Location map and sampling points for surface and groundwater

Soil contamination levels were determined from sampled sites as presented in Figure 6.3, by comparing the data sets with established guidelines and standards. Alternatively, these data sets can also be compared with control sites. Control sites are areas that are known to be unaffected by, in this case, oil spills. Comparison with control sites and established standards were jointly used to ascertain contaminant threshold values. Univariate statistical analysis was applied to soil and sediment samples establish central tendencies and dispersion of contaminants.

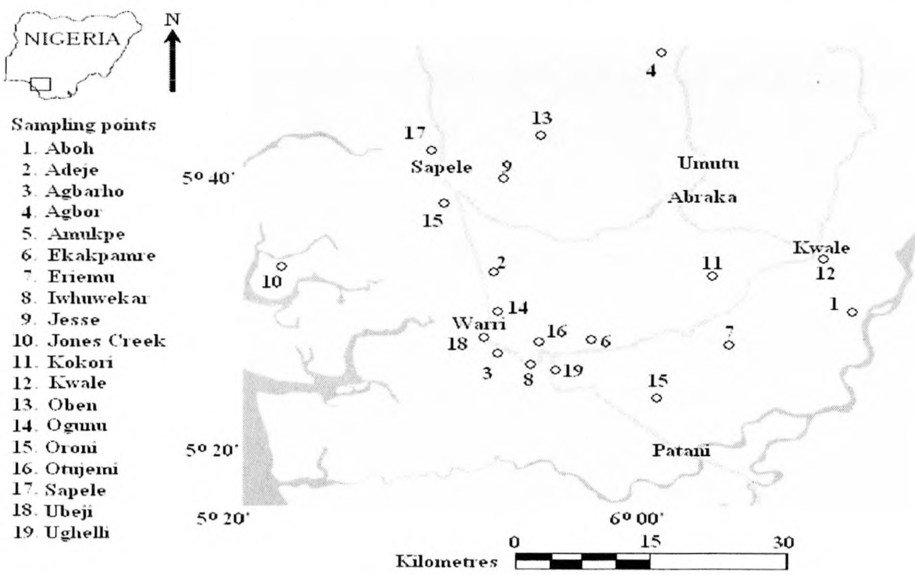


Figure 6.3: Location map showing soil sampling points

6.4 Results and Discussion

6.4.1 Results

6.4.1.1 Principal component analysis and factor analysis

Factor analysis (FA) was performed by Principal component analysis (PCA) extraction method (Aruga et al., 1995, Liu et al., 2003, Parinet et al., 2004). The rotation of the principal components was executed by the Varimax method with Kaiser Normalization. Results of the Varifactors (VF) from the Varimax rotation are displayed in Tables 6.1 and 6.2.

Table 6.1: Loading for varimax rotated factor matrix of five-factor model explaining 77.11% of the total variance for surface water

Varifactors Parameters	VF1	VF2	VF3	VF4	VF5
Biochemical Oxygen Demand	**.950**	-.011	.020	.178	.006
Magnesium	**.941**	-.019	.013	.191	-.046
Potassium	**.930**	-.057	.057	.184	-.092
Sodium	**.907**	-.047	.059	.155	-.082
Nitrate	**.892**	-.091	-.006	.266	-.035
Chemical Oxygen Demand	**.839**	.040	.126	.050	.061
Total Dissolved Solids	**.805**	.044	.413	6.08E-005	.038
Nickel	**.617**	**.514**	-.094	-.178	.206
Iron	-.204	**.839**	.073	-.042	.007
Turbidity	-.115	**.792**	-.113	-.073	-.265
Dissolved Oxygen	-.279	**-.641**	-.083	-.221	-.051
Electrical Conductivity	-.067	.040	**.961**	-.062	.006
Sulphate	.452	-.017	**.834**	.109	.026
Total Petroleum Hydrocarbon	.232	.021	-.010	**.882**	-.014
Zinc	**.556**	.003	.054	**.637**	.146
pH	.061	-.342	-.048	.030	**.752**
Temperature	-.041	-.040	.304	.129	**.750**
Lead	.070	-.193	.202	.089	-.435
% of Total Variance	37.33	12.12	11.04	8.40	8.22
Cumulative % variance	37.33	49.45	60.49	68.89	77.11

Table 6.2: Loading for varimax rotated factor matrix of five-factor model explaining 80.55% of the total variance for groundwater

Varifactors / Parameters	VF1	VF2	VF3	VF4	VF5	VF6
Sodium	**.975**	.093	.074	.063	-.005	-.022
Electrical Conductivity	**.971**	-.128	-.027	.068	-.024	-.055
Potassium	**.925**	.020	.046	.176	-.028	.017
Total Dissolved Solids	**.828**	.398	.263	.022	.029	-.008
Biochemical Oxygen Demand	.021	**.895**	.342	.003	-.134	.075
Sulphate	.024	**.878**	.378	-.018	-.029	.086
Chemical Oxygen Demand	.128	**.869**	.229	.105	.003	-.016
Nitrate	.003	**.661**	-.271	-.076	.499	.052
Iron	-.038	.116	**.954**	.040	.133	.035
Magnesium	.165	.307	**.865**	.025	.044	.056
Zinc	.160	.398	**.698**	-.138	-.190	-.124
Turbidity	.144	.038	-.064	**.744**	-.359	-.251
Nickel	-.054	-.236	.055	**.679**	.284	.290
Dissolved Oxygen	-.210	-.316	-.053	**-.630**	-.233	.218
Total Petroleum Hydrocarbon	.432	.003	-.114	**.538**	-.295	.274
Lead	.000	-.024	.077	.010	**.840**	-.024
Temperature	.115	-.041	.065	-.065	-.193	**-.793**
pH	.120	.090	.102	-.133	-.321	**.645**
% of Total Variance	21.05	18.79	14.73	10.00	8.45	7.53
Cumulative % variance	21.05	39.84	54.57	64.57	73.02	80.55

6.4.1.2 Cluster analysis

To detect spatial similarity among groups, CA was applied to the fifteen sampling sites. The Ward's method was applied (linkage between groups), using euclidian distance as similarity measure and the results were synthesized in dendrograms (Helena et al., 2000, Panda et al., 2006). CA was performed separately on surface and groundwater. Figures 6.4 and 6.5 present the results, as illustrated by dendrograms.

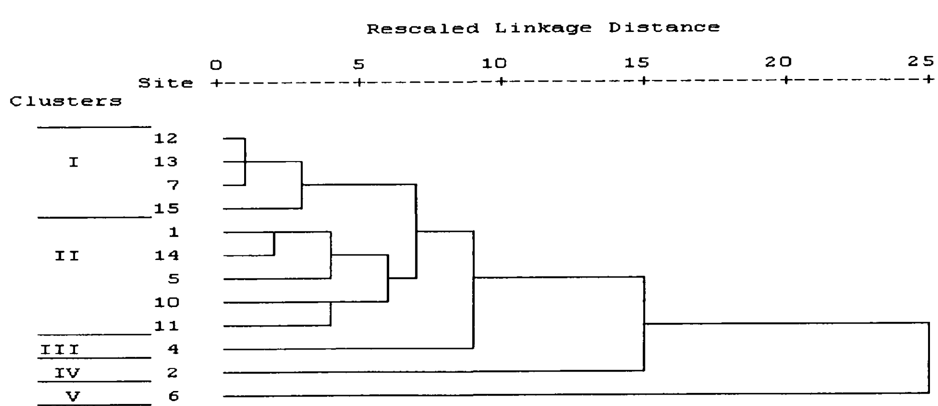


Figure 6.4: Dendrogram of relationship among sampling sites for surface water. Each group indicates sites of similar physico-chemistry

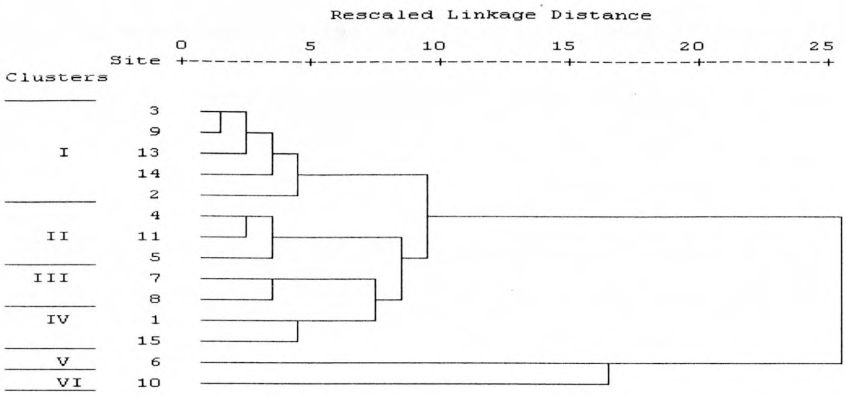


Figure 6.5: Dendrogram showing relationship among sampling sites for groundwater. Each group indicates sites of similar physico-chemistry

6.4.1.3 Univariate analysis

Soil samples were subjected to univariate statistical analysis to determine the level of pollution between spill sites and control sites. The results are displayed in Figure 6.6 for heavy metals and Figure 6.7 for pH, TOC and TPH.

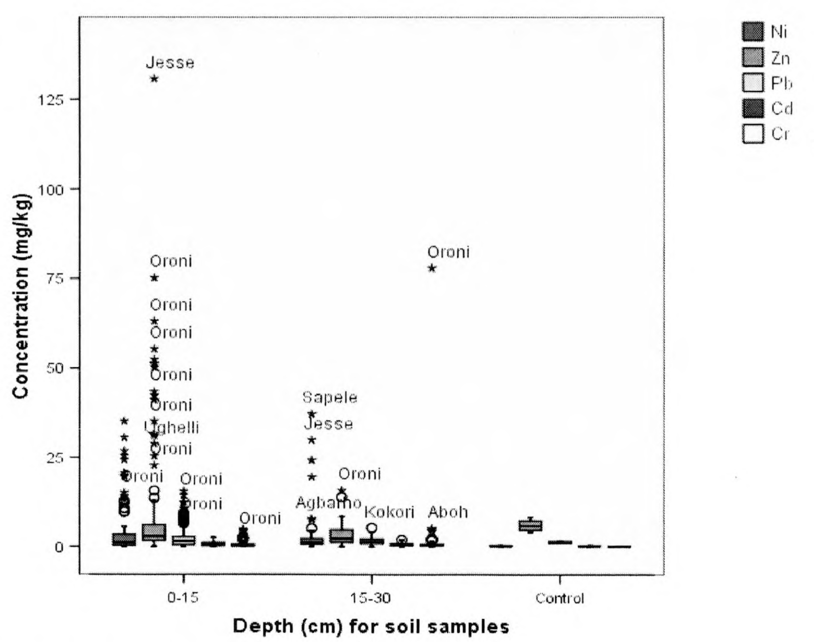


Figure 6.6: Boxplot of heavy metals in soil samples

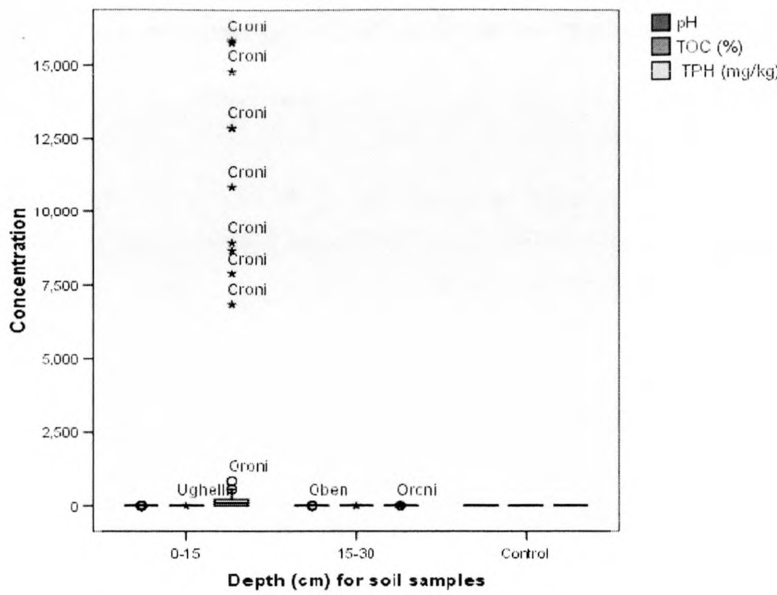


Figure 6.7: Boxplot of ph, TOC and TPH for soil samples

6.4.2 Discussion

6.4.2.1 Source identification using principal component analysis and factor analysis

6.4.2.1.1 *Surface water*

Table 6.3 shows the result of PCA/FA, and indicates 5 main controlling factors underlying the chemistry of surface water in the study area.

Table 6.3: Summary of cluster sampling sites with physico-chemical variables and dominant processes for surface water

Groups	Sampling sites*	Physico-chemical variables	Dominant processes
I	12-13-7-15	Na, K, NO_3, Mg, BOD, COD, TDS, Ni	Industrial, domestic and agricultural pollution
II	1-14-5-10-11	Zn, TPH	Hydrocarbon pollution
III	4	Turb, Fe	Surface runoff and erosion of lateritic soil
IV	2	EC, SO_4	Atmospheric pollution
V	6	pH, Temp	Vegetal effect

*Note: No surface water sample was collected at sites 3, 8 and 9

Factor I explains 37.33% of the total variance and includes a strong loading of TDS, BOD, COD, NO_3, Na, K and Mg, and a moderate loading of Ni and Zn. The strong correlation between NO_3, Na, K and Mg suggests a common source. This factor may be related to anthropogenic pollution of industrial, domestic and agricultural sources. Zn and Ni correlate poorly (r = 0.33) (Omo-Irabor et al., 2008), which may suggest different or multiple sources. Zn may be sourced from effluent from the chemical industry (Nasiman, 1996) and from lubricating oils (De Miguel et al., 1997) or from tyre wears in urban areas (Ellis and Revitt, 1982). The enhancement of Ni in rivers have been linked to sewage effluent (Dassenakis et al., 1998) or agricultural sources (Mendiguchia et al., 2007).

Factor II explains 12.12% of total variance in the data set and consists of a strong loading of Turbidity and Fe and a moderate loading of Ni, This factor can be attributed to inputs into river by surface runoff and erosion processes. The equatorial climatic conditions that foster rain in excess of 3000mm annually (Iloeje, 1981) coupled with the loose and lateritic Benin Formation underlying most of the study area (Olobaniyi et al., 2007) are favourable conditions for sheet and gully erosion. Consequently, turbid water laden with leached iron (from the lateritic sediments) and Ni (from industrial dumps and agricultural sources) are emptied into the rivers. The negative factor loading of DO and pH on this factor suggests utilization of dissolved oxygen in the ferrous to ferric conversion accompanied by H^+ released into the system.

Factor III explains 11.04% of total variance and consists of a strong loading of EC and SO_4. This factor can be related to atmospheric pollution from gaseous emissions into the atmosphere from petroleum related industrial and vehicular exhausts. Previous reports have indicated that, within the study area, SO_2 is emitted into the atmosphere at a yearly rate of 400,000 tons (Ogunkoya and Efi, 2003). This SO_2 emission has been implicated in enhanced rainfall acidity and ecosystem degradation in the area (Olobaniyi and Efe, 2007). Rivers within this area is partly replenished both from direct rainfall and resulting floodwater from soil surface runoff.

Factor IV accounts for 8.40% of total variance and consists of high and moderate loadings of TPH and Zn, suggesting pollution from the numerous oil spills experienced annually in the area. Factor V represents 8.22% of total variance and probably represents the influence of vegetal cover. Sections of the stream that are shielded by water hyacinth vegetation experience lower temperature and also higher acidity resulting from organic acids derived from decaying leaves that fall into the rivers. The physico-chemical effect of increasing pH is reflected in the weak negative loading of Pb on this factor.

6.4.2.1.2 *Groundwater*

Factor analysis of groundwater chemical variables produced 6 factors, accounting for 80.55% of the total variance of the data set, as shown in Table 6.4.

Table 6.4: Summary of cluster sampling sites with physico-chemical variables and dominant processes for groundwater

Groups	Sampling sites*	Physico-chemical variables	Dominant processes
I	3-9-13-14-2	EC, Na, K, TDS	Soil and groundwater interaction
II	4-11-5	Turb, TPH, Ni	Hydrocarbon and domestic pollution
III	7-8	Pb	Atmospheric and vehicular pollution
IV	1-15	pH	Physico-chemical reactions
V	6	BOD, SO_4, COD, NO_3	Domestic and agricultural pollution
VI	10	Mg, Fe, Zn	Industrial pollution

*Note: No groundwater sample was collected at site 12

Factor I accounts for 21.05% of the total variance and has a strong loading of TDS, EC, Na, K and Mg, and can be ascribed to natural hydrogeochemical evolution of groundwater by groundwater geological medium interaction. The secondary loading of TPH on this factor however indicates some effect of hydrocarbon percolation into the geological medium from the incessant oil spillage in the study area. Factor II accounts for 18.79% of the total variance with a strong loading of BOD, COD, SO_4, and NO_3 and indicates anthropogenic pollution from domestic and agricultural sources. This factor is partly reflected in significant microbial contamination of groundwater in the area (Ejechi et al., 2007). Recent investigation also indicates that groundwater within the study area is being contaminated through the use of nitrogen based fertilizers (Olobaniyi et al., 2007).

Factor III explains 14.73% of total variance in the data and has a strong contribution from Mg and Fe and moderate contribution from Zn. This factor suggests significant contribution of metallic ions into groundwater from metallic scraps and dumps. In addition, this area hosts a prominent steel making industry. Factor IV explains 10.00% of total variance and consists of a strong to moderate loadings of Turbidity, Ni and TPH which accounts for the diminished DO content. This factor can be related to groundwater contamination from hydrocarbon sources. In this study area, a yearly average of 270 oil spills contributing to approximately 100,000 barrels/year of oil, have been recorded over a 20 year period (1976-1996) (Nwilo and Badejo, 2001). The friable nature of the underlying formations coupled with the shallow aquifer levels in the area enhances the ready access of hydrocarbon from such spills into groundwater.

Factor V explains 8.45% of total variance in the data set. The factor is dominated by Pb and weak loading of NO_3. This factor relates to anthropogenic pollution from vehicular exhaust and gaseous emissions from the petroleum refining industries in the area. Pb and greenhouse gases ejected into the atmosphere are dissolved by rainwater and recharge of groundwater. Nevertheless the weak correlation between Pb and NO_3 ($r = 0.326$) suggests multiple sources for NO_3 including domestic and agricultural (Omo-Irabor et al., 2008). Factor VI accounts for 7.53% of the variance and consists of moderately positive and strongly negative loadings of pH and temperature respectively. This factor probably represents the source of physico-chemical variations in the system.

6.4.2.2 Spatial similarity and sample site grouping using cluster analysis

6.4.2.2.1 *Surface water*

Surface water samples were collected from 12 of the 15 sampling sites, and these fell into five major clusters as presented in Figure 6.4 and Table 6.3. These clusters are also represented spatially in Figure 6.8. Cluster I consists of 12(Opukushi), 13(Otujeremi), 7(Jones Creek) and 15 (Utorogu) and reflects the processes dominated by Factor I. Cluster II is predominant around 1(Adeje) and 14 (Ughelli) and corresponds with hydrocarbon polluted sites which are reflected in Factor IV. Cluster III is associated with surface runoffs and erosion of lateritic soils (Factor II around location 4(Eriemu). Cluster IV represents the influence of atmospheric pollution reflected in Factor III and site 2(Amukpe). Cluster V indicates vegetal activities and is dominant around 6(Jesse).

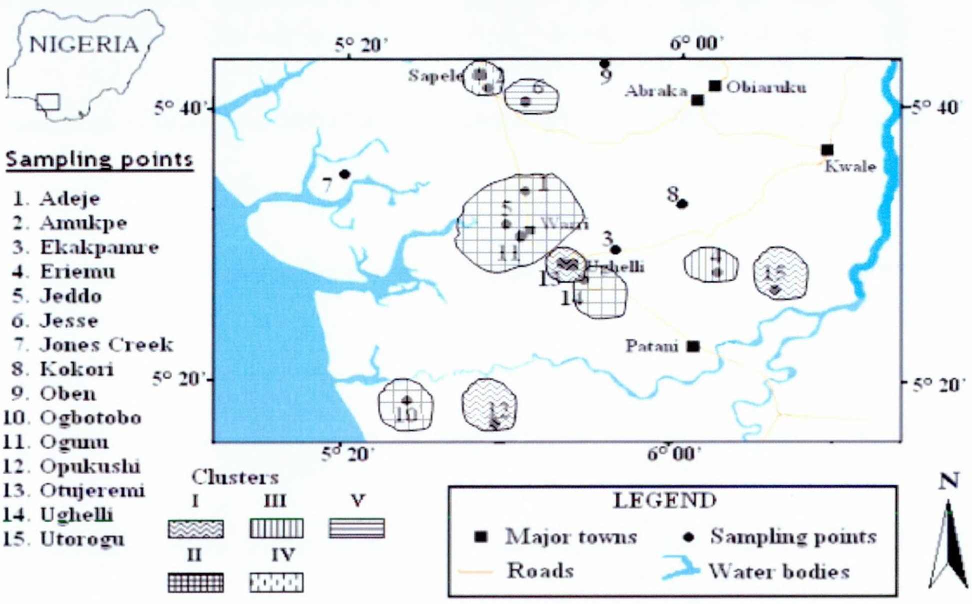


Figure 6.8: Spatial distribution of sampling sites clusters for surface water

6.4.2.2.2 *Groundwater*

A total of six clusters of sampling sites were obtained from the groundwater physico-chemical parameters, as displayed in Figure 6.5 and Table 6.6 and spatially represented in Figure 6.9. Cluster I consists of location 3(Ekpapamre), 9(Oben), 13(Otujeremi), 14(Ughelli) and 2(Amukpe) and reflects the effect of soil-groundwater interaction. This cluster indicates the activity of Factor I. Cluster II reflects hydrocarbon pollution (Factor IV) and is spatially represented in sites 4(Eriemu), 11(Ogunu) and 5(Jeddo). Cluster III comprises of site 7(Jones Creek) and 8(Kokori). This cluster reflects areas with the greatest influence of Factor V. Cluster IV represents the influence of pH (Factor VI) in the system and is mostly reflected in sites 1(Adeje) and 15(Utorogu). Cluster V indicates the areas with the greatest influence of domestic and agricultural pollution (Factor II) and is most prominent around site 6 (Jesse). Cluster VI shows areas with the greatest influence of Factor III.

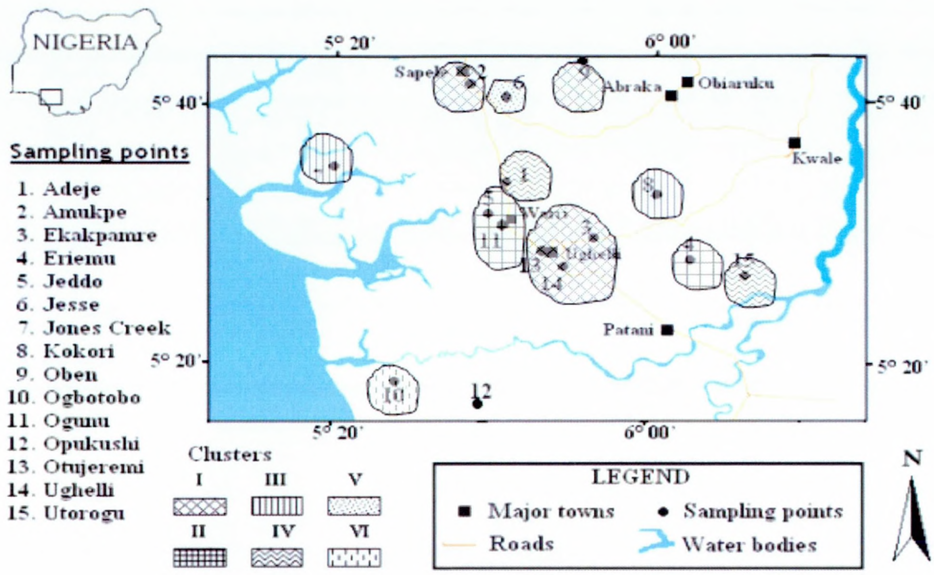


Figure 6.9: Spatial distribution of sampling sites clusters for groundwater

6.4.2.3 Level of soil contamination

Figure 6.6 shows heavy metal constituents of soil samples collected from oil spill and control sites. At soil depths 0-15cm, Oroni presented outliers in all heavy metals measured with the exception of Cd thus indicating a high level of heavy metal contamination. Jesse and Ughelli presented outliers in Zn.

At 15-30cm depth, Agbaroh, Jesse and Sapele presented outliers for Ni. Oroni presented outliers for Zn and Cd, while Kokori and Aboh presented for Pb and Cr respectively. Figure 6.7 displays a high level of TPH contamination for Oroni. Due to the absence of standards for the measurement of TPH, samples were compared against those obtained for control sites. Results indicate that areas close to oil facilities that have experienced oil spills recorded high levels of heavy metals and TPH.

6.5 Summary

The application of multivariate statistical techniques has been used to establish the nature and spatial distribution of physico-chemical variables that reflect natural and anthropogenic activities in surface and groundwater within the western Niger Delta region. The varifactors obtained from factor analysis indicate that the processes responsible for water quality variations in surface water are 1. Industrial, domestic and agricultural pollution. 2. Hydrocarbon pollution. 3. Soil erosion activities. 4. Atmospheric pollution and 5. Vegetal effect. For groundwater the dominant varifactors are explained by the following processes. 1. Soil-groundwater interaction. 2. Domestic and agricultural pollution. 3. Industrial pollution. 4. Hydrocarbon pollution. 5. Atmospheric and vehicular pollution and 6. the effect of pH on the system.

The intensity of these factors, as reflected by sampling location clusters, indicates a rather unsystematic and random nature which reflects the multipurpose nature of land use in the study area. Therefore, proper land use planning is imperative in this oil producing region for effective surface water and groundwater monitoring and management.

Chapter 7 : Environmental Vulnerability Assessment of Targets[3]

7.1 Introduction

This chapter utilizes the developed MCDS framework for the environmental vulnerability assessment of targets (receptors) exposed to oil related activities. Special emphasis is placed on the vulnerability of targets such as humans, water and vegetation located within close proximity to production and transportation sites as discussed in section 3.5. Multi-criteria analysis (MCA) was applied for derivation of vulnerability indices of targets (receptors) of oil activities. MCA is a set of evaluation methods that attempts to help decision makers in situations when judgement depends on more than one criterion (see section 3.4.4. for details). MCA was applied in the weighting and scoring of identified criteria for environmental vulnerability assessment of receptors such as humans (rural populace), water and vegetation. The concept is to develop vulnerability indices for each of the possible targets. In other to achieve this, it was thus necessary to select relevant criteria that closely reflect the impact of oil activities. The major emphasis of this chapter is the identification and assignment of appropriate weights to criteria which can be used in

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[3] Aspects of Chapter 7 are documented in:
Omo-Irabor O.O., Oduyemi K., Akunna J. and Ekanem E. 2008. Multi-criteria decision analysis (MCDA) approach to conflict management using of stakeholder participation and Millennium Development Goals (MDGs) agenda. Conference Proceedings of the *1st Postgraduate Researchers' Conference (Postcon2008)*, 29-30 September 2008, University of Abertay, Dundee, United Kingdom

Paradzayi, C. and Omo-Irabor O. 2008. Mapping Nypa colonization of mangrove environments – Potential for Radar remote sensing in the Niger Delta. Conference Proceedings of the *1st Postgraduate Researchers' Conference (Postcon2008)*, 29-30 September 2008, University of Abertay, Dundee, United Kingdom

Omo-Irabor O.O., Olobaniyi S.B., Oduyemi K., Akunna J., Venus V. and Maina J.M. 2008. Mangrove vulnerability assessment using satellite images, multi-criteria analysis (MCA) and GIS techniques. A paper presented at the *7th International Remote Sensing Conference on Application of Earth Observation and Geoinformation for Governance in Africa,* 27-30 October, 2008, Accra, Ghana the production of vulnerability/susceptibility maps for planners and policy/decision makers.

7.2 Human Vulnerability Assessment

Human vulnerability assessment outlined in section 3.5.1.1 emphasised on the rural populace and aspects of their sustenance such as farming and fishing. The methodology, utilized for the assessment involves, aspects of environmental decision making as discussed in section 3.4 and includes:

1. Definition of alternatives: identify the policy alternatives which are to be compared with each other;
2. Selection and definition of criteria: identify the effects or indicators relevant for the decision;
3. Identification and participation of Stakeholders: identify relevant stakeholder for the assignment of criteria scores and weights
4. Stakeholder questionnaire survey: solicit scores and weights among stakeholders
5. Estimation of scores and weights for each alternative: assign values for each effect or indicator for all alternatives.

7.2.1 Selection and definition of criteria

Two sets of indicators were applied for the vulnerability assessment for this study – those derived for Potential Impact Assessment (PIA) and Adaptive Capacity (AC). As mentioned in section 3.6.2.1.(i), PIA was assessed from three main criteria (these were found to be exhaustive enough for the assessment):

1. The risk posed by oil facilities
2. Exposure of ecosystem and rural populace
3. Sensitivity of the landscape to pollution

The criteria used for evaluating AC were obtained from the United Nation Millennium Development Goals (MDGs) agenda and the Federal Government of Nigeria seven point agenda as discussed in section 3.6.2.1.(ii). These were found to be encompassing enough for the assessment of AC particularly for this study and for similar studies around the world.

7.2.1.1 Potential impact assessment of environmental criteria

The data required for the PIA were both spatial (maps) and non-spatial (attribute columns/tables) and are summarized in Table 7.1.

Table 7.1: Criteria and sub-criteria for potential impact assessment

Criteria	Sub-criteria	Unit
Risk posed by oil facilities	Type of oil facility	index
	Age of oil facility	years
	Type of spill	index
	Estimated volume of spill	m^3
	Estimated area coverage of spill	m^2
Exposure of ecosystem and rural populace	Distance of oil facility to rural settlements	m
	Distance of oil facility to agricultural land	m
	Distance of oil facility to surface water bodies	m
	Distance of oil facility to forest	m
	Size of population affected	index
Sensitivity of the landscape to pollution	Topography	%
	Hydraulic soil property	index
	Depth to water table	m
	Geology	index

The sub-criteria were measured in different units as shown in Figure 7.1. It was quite challenging attempting to incorporate the different criteria required for the derivation of PIA. The Integrated Land and Water Information System (ILWIS)-Spatial Multi-criteria Evaluation (SMCE) was selected for the evaluation of PIA. SMCE window in ILWIS is an application that assists and guides a user in doing Multi-Criteria Evaluation (MCE) in a spatial way. ILWIS-SMCE consists of three phases – problem analysis, design of alternatives and decision making from alternative options. SMCE, also referred to as Spatial Multi-criteria Analysis (SMCA) method was used for determining relative importance of conditions affecting the rural populace and their immediate environment. Aggregation of data followed path1 as presented in section 3.4.4.

7.2.1.1.1 *Preparation of data layers and tables*

The first step in PIA was to prepare the input data in two different formats. The Nigeria-sat satellite image obtained from NASRDA, Abuja provided the co-ordinate system and geo-reference that was applied to all the maps created as provided in Figure 7.1.

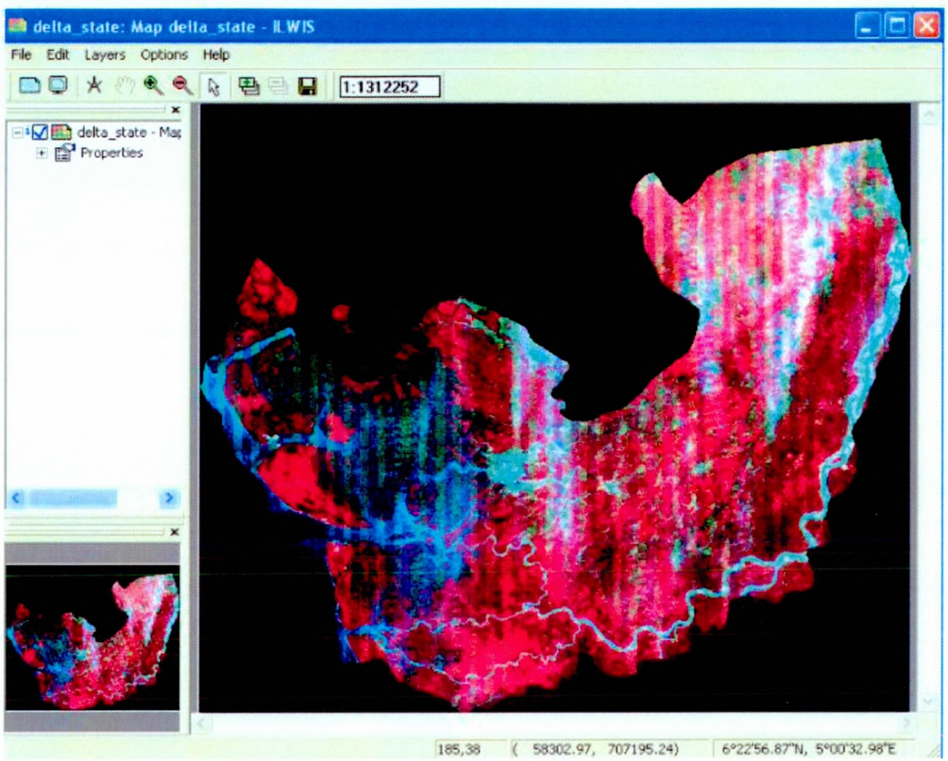

Figure 7.1: Satellite image used for geo-referencing all spatial data (Source: NARSDA)

A common co-ordinate system (for vector data) and/or geo-reference (for raster data) is required for merging of data layers. The boundary of the study area was created by on-screen digitization of the satellite image and geology map. All spatial maps were converted to raster while others were stored in columns of attribute tables that were linked to one of the raster maps. Raster format is made of pixels (picture elements) of a certain size, e.g. 30m x 30m spatial resolution. In the case of this work a 30m pixel size was selected. This was done in order for the other maps to correspond to the classified landcover map derived from Landsat satellite images as shown in Figure 7.2.

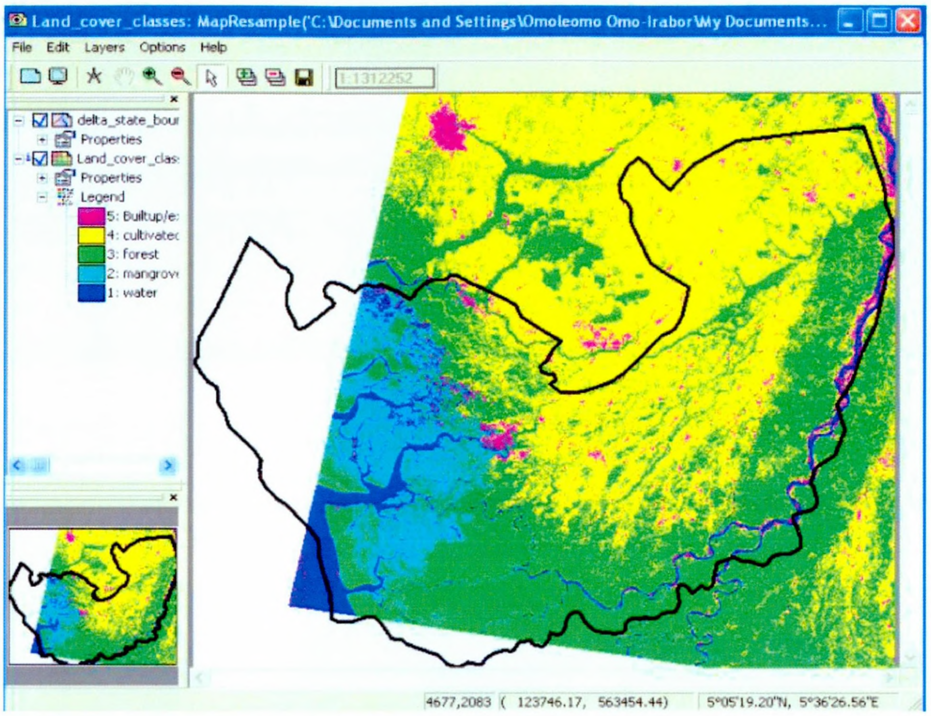

Figure 7.2: Landcover classes with 30 m spatial resolution

7.2.1.1.2 *Construction of criteria tree*

After all the datasets required for PIA have been assembled, the next step was the construction of criteria tree using the SMCE mode in the ILWIS software as illustrated in Figure 7.3. The criteria tree is a tree whose root is the main goal defined by the researcher. In this case, the main goal is the potential impacts of oil activities on rural inhabitants. The leaves of the tree are the criteria required to evaluate the performance of the main goal while the branches divide the main goal into partial goals. A criterion can be a constraint or a factor as discussed in section 4.4.4.3. The constraints identified in this study were urban areas. Since the focus of vulnerability assessment was on the rural populace, urban areas were excluded from further analysis by the assignment of a zero value. This implies that there is no compensation for other information for urban areas. The factors identified included risk, exposure and sensitivity (refer to section 3.6.2.1 for more details).

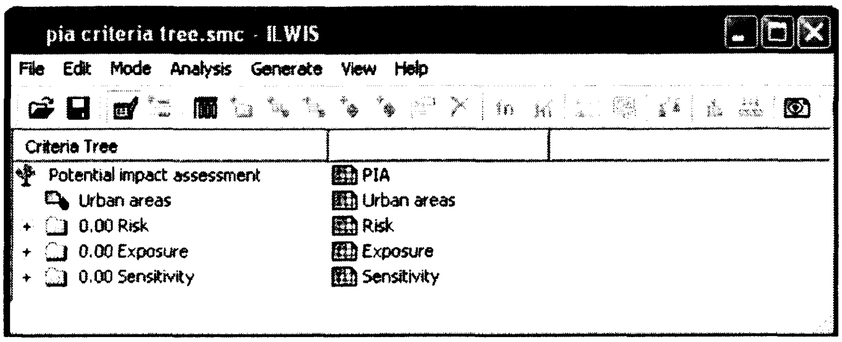

Figure 7.3: Criteria tree for potential impact assessment (PIA)

Figure 7.4 represents the main factors or criteria which were further divided into sub-criteria for ease of analysis. It is essential to note that a criterion can be a cost or benefit to the overall assessment. Cost (C) and benefit (B) as used in this research does not imply financial loss or gain, but that an increase in the criteria will lead to an increase in the potential impact and vice versa.

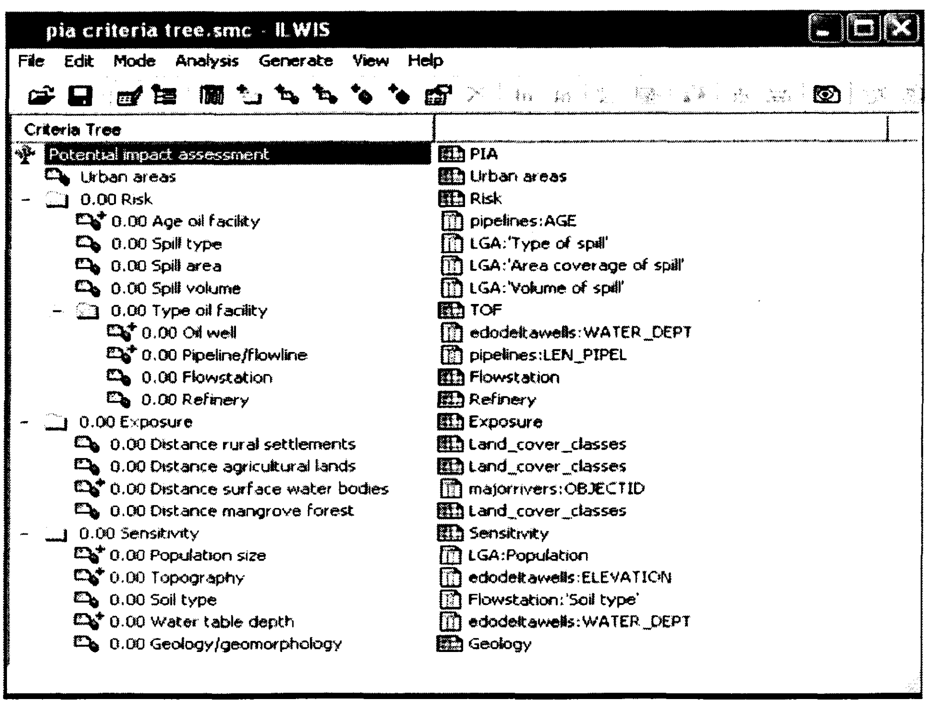

Figure 7.4: Sub-criteria tree for potential impact assessment (PIA)

Data sets for the 'Risk' component of the tree were collected from the Department of Petroleum Resources (DPR) and Shell Petroleum Development Corporation (SPDC). They were all in attribute column format linked to raster maps of pipelines and LGA of Delta State. While DPR provided data on oil spill characteristics as listed in Table 4.2, SPDC with the permission from DPR provided information on the types and location of oil facilities as shown in Appendices A.2.3 and A.2.4.

The 'Exposure' branch of the tree was mainly obtained from the classified Landsat image in Chapter 5. Information on surface water bodies was augmented with SPDC data. Due to the narrow nature of rivers, it was difficult to classify most of them especially when they are cover by dense vegetation. The use of information of major rivers from SPDC as displayed in Appendix A.2.5, helped to solve the problem.

Information for 'Sensitivity' was acquired from different sources. As a result of the difficulty in obtaining census data as at the time this study was undertaken, the researcher had to use primary school enrolment figure (Delta State, 2008), to obtain the relative population of the Local Government Areas (LGAs) in the study area. Topography, soil type and depth to water table were all obtained from SPDC. Geology map was digitized from the pdf version of Geology map of Nigeria as provided in Appendix A.2.2

7.2.1.2 Adaptive capacity using socio-economic criteria

As already mentioned in section 3.5.1.1 (ii), criteria for AC were obtained from two sources, namely - the UN Millennium Development Goals (MDGs) and the Federal Government of Nigeria seven-point agenda (FGNSPA). The criteria of MDGs agenda were chosen because they take into consideration the socio-economic conditions that are important to inhabitants of a place and will have wide applicability worldwide. These are shown in Figure 7.5.

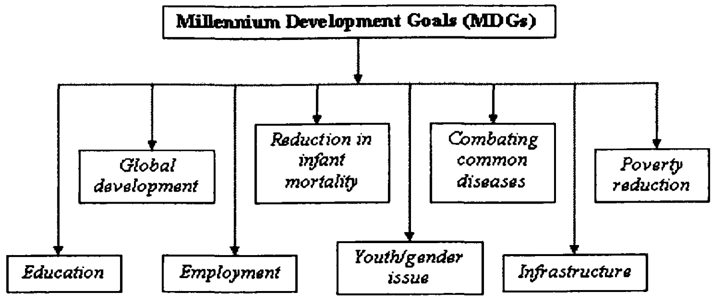

Figure 7.5: UN Millennium Development Goals

Figure 7.6 depicts the FGNSPA that was also included for the AC assessment. This was necessary to add to the robustness of criteria used for the determination of AC.

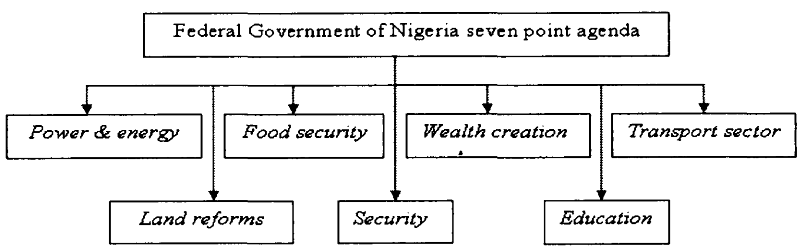

Figure 7.6: Federal Government of Nigeria (FGN) Millennium Development Goals

From the lists of MDGs and FGNSPA, 12 criteria were finally selected with expert consultation for AC evaluation as displayed in Figure 7.7.

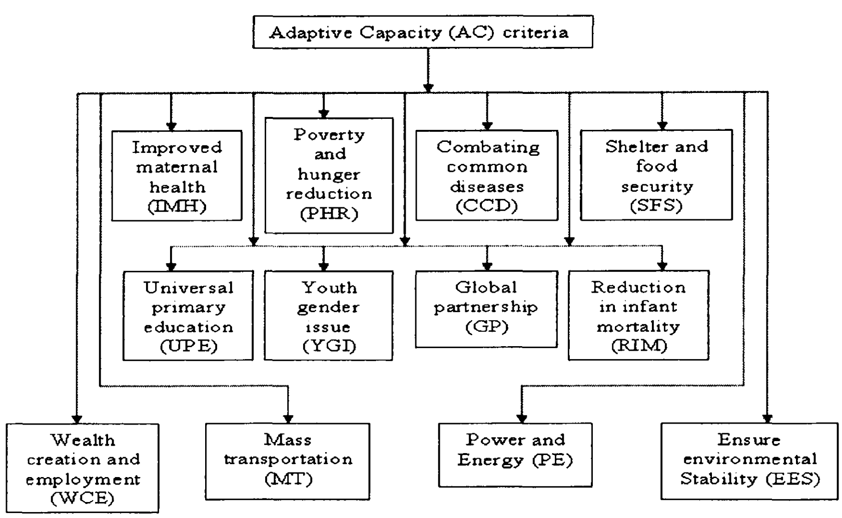

Figure 7.7: Identified criteria for adaptive capacity (AC) evaluation

7.2.2 Stakeholder/expert participation in questionnaire survey

Several stakeholders/experts were involved in the assessment process of this research work, as outlined in section 4.4.1. The framework required the accommodation of information from stakeholders and experts through questionnaire survey. This was necessary due to the dearth in empirical data for a research of this nature. Two sets of participants were approached. The first comprised of experts in oil related organisation and in the field of natural resources, while the second set was made up of members of host communities in Delta State

7.2.3 Assignment of scores and relative importance of criteria

7.2.3.1 Potential impact assessment

Score assignment for PIA was achieved through participatory group discussion involving experts made up of lecturers in one of the tertiary institution located in the study area. The researcher who headed the group discussion requested input on the scores to be assigned for each of the classes for the sub-criteria of PIA. The scores were assigned in such as manner that all sub-criteria were benefits to the overall objective (i.e. a high value implies a positive effect). The scores which varied from 1 – 5 that were finally agreed upon are displayed in Table 7.2.

Table 7.2: Criterion scores (raw) for Potential impact assessment

Criteria	Sub-criteria	Classes	Score
Risk	Type of facility	Oil well	1
		Pipeline/flowline	2
		Flowstation	3
		Refinery	3
	Age of facility	Less than 5 years	1
		5 to less than 10 years	2
		10 to less than 20 years	2
		Greater than 20 years	3
	Type of spill/emission	Gas	5
		Petrol	4
		Kerosene	3
		Diesel	2
		Crude oil	1
	Volume of spill	Less than 2500 m^3	1
		Greater or equal to 2500 m^3	2
	Area coverage	Less than 1600 m^2	1
		Greater or equal to 1600 m^2	2
Exposure	Distance to rural settlements	0 to less than 100 m	4
		Greater or equal to 100 m	2
	Distance to agricultural lands	0 to less than 250 m	3
		Greater or equal to 250 m	1
	Distance to surface water bodies	0 to less than 250 m	3
		Greater or equal to 250 m	1
	Distance to forest	0 to less than 500 m	2
		Greater or equal to 500 m	1
Sensitivity	Size of population affected	Less than 1000	2
		1000 to 5000	3
		Greater than 5000	4
	Topography (slope)	Less than 8 %	1
		Greater or equal to 8 %	2
	Soil type	Gravel	4
		Sand	3
		Silt	2
		Clay	1
	Depth to water table	0 to less than 5 m	3
		5 to less than 10 m	2
		Greater or equal to 10 m	1
	Geology/Geomorphology	Coastal Plain sands	4
		Sombreiro-Warri plains	3
		Floodplain	2
		Mangrove swamp	2

The scores assigned to each criterion in Table 7.2 were dependent on their overall effect on the vulnerability of the rural populace and their sources of sustenance (e.g. farming and fishing). Although soil type and geology/geomorphology appear to be similar, the soil type refers to the characteristics within the immediate vicinity of the area being assessed, if for instance clay is the soil type, it would be easier to contain any spill compared to if it was sand or gravel. The geology on the other hand is the characteristics on a regional scale with focus on the impact on the subsurface features (e.g. aquifers) being of more significance.

For the relative importance of the main criteria and sub-criteria for PIA the grouped median values of the experts were used, as displayed in Tables 7.3 and 7.4. The mean and standard deviation were included, solely for the purpose of showing the variation among experts.

Table 7.3.: Summary of statistics for criteria from experts (lecturers) for potential impact assessment criteria

	Experts					
	Geol	Micro	Chem	Grouped median	Mean	SD
Criteria						
Risk	4.43	4.75	4.00	4.43	4.39	0.38
Exposure	4.20	3.75	3.50	3.88	3.82	0.35
Sensitivity	3.43	4.50	3.50	3.73	3.81	0.60

From the results of the main criteria for PIA, risk posed by oil facilities was weighted the highest by all experts with a grouped median of 4.43. Exposure had the lowest variation among experts with SD of 0.35. By taking into consideration the views of experts in different fields of specialization, the subjective nature of the MCA approach is reduced.

Table 7.4: Summary of statistics for PIA sub-criteria from experts (lecturers) for potential impact

		Experts					
		Geol	Micro	Chem			
Criteria	Sub-criteria				Grouped median	Mean	SD
Risk	R1	3.60	4.00	3.50	3.78	3.86	0.31
	R2	3.50	4.00	3.33	3.67	3.79	0.41
	R3	3.83	3.33	4.00	3.75	3.89	0.29
	R4	3.67	3.50	3.67	3.60	3.63	0.12
	R5	3.71	3.50	3.50	3.58	3.90	0.38
Exposure	E1	4.43	4.50	3.80	4.33	3.98	0.38
	E2	4.33	4.25	4.00	4.33	4.28	0.26
	E3	4.43	4.50	3.33	4.23	4.14	0.51
	E4	3.67	3.50	3.33	3.50	3.33	0.28
Sensitivity	S1	3.50	3.67	4.00	3.67	3.80	0.40
	S2	3.00	3.50	3.00	3.14	2.97	0.33
	S3	3.50	3.33	2.75	3.22	3.10	0.34
	S4	3.60	4.50	3.33	3.80	3.78	0.45
	S5	3.60	4.33	2.75	3.50	3.79	0.72

In the sub-criteria group, 'Distance of oil facility to rural settlement' (E1) and 'Distance of oil facility to agricultural lands' (E2) ranked the highest with grouped median value of 4.33 each while the lowest was 'Topography' (S2) (3.14). Experts were more consistent with the weights they assigned to 'Estimated volume of spill' (R4). This gave a standard deviation (SD) of 0.12.

7.2.3.2 Adaptive Capacity

After the questionnaire survey (as outlined in section 4.4.2), SPSS Statistical package was used to calculate the univariate (median, grouped median, range, mean and standard deviation) statistics of the objectives and the sub-objectives from individual scores on a scale of 1-5 (weights) and 1-3 (scores), as presented in Appendices C.3 and C.4 respectively. The mean and standard deviation were only included to provide an indication of the dispersion of scores. As with non-parametric analysis of this nature, the grouped median provides a more meaningful descriptive statistics of the results (refer to section 3.6.2.2).

Weights were elicited from two groups of experts as discussed in section 4.4.1. A summary of the weights are presented in Table 7.5

Table 7.5: Summary of weights (grouped median, mean and standard deviation) from experts for millennium development goals criteria

	Group 1 (GP1)			Group 2 (GP2)			Total Median	Total median		
Experts	Oil Comp	DPR	FMEn	Geol	Micro	Chem	(GP1)	(GP2)	Mean	SD
MDGs										
WCE	4.57	3.83	4.25	4.17	4.50	4.60	4.33	4.43	4.32	0.30
IMH	3.67	4.00	4.00	3.50	3.67	4.50	4.09	4.00	3.89	0.36
UPE	4.00	4.00	4.50	4.14	4.25	4.00	4.15	4.23	4.15	0.20
PHR	4.83	4.00	4.33	4.20	5.00	4.50	4.40	4.54	4.48	0.38
YGI	3.50	3.00	3.67	3.60	4.33	3.00	3.40	3.50	3.52	0.50
GP	3.67	3.60	4.00	2.80	4.33	3.50	3.71	3.44	3.65	0.52
RIM	4.00	4.00	3.67	3.40	4.00	4.00	4.00	3.71	3.85	0.25
CCD	4.67	3.50	3.25	3.00	4.33	4.50	4.08	3.83	3.88	0.71
SFS	4.20	3.50	4.00	4.00	4.33	4.50	3.83	4.25	4.09	0.35
PE	3.80	4.00	5.00	3.50	3.50	4.20	4.23	3.86	4.00	0.56
MT	2.60	2.80	3.00	3.17	3.00	3.00	2.77	3.08	2.93	0.20
EES	4.40	3.17	4.50	3.20	4.00	3.75	3.90	3.55	3.84	0.57

The scores (grouped median) for AC criteria that were obtained from host community members of 20 out of the 25 LGAs in Delta State are presented in Table 7.6. Stakeholders for the excluded five LGAs could not be reached at the time the survey was done.

Table 7.6: Summary of score (grouped median) for AC criteria from stakeholders (community members from local government areas in Delta State)

AC LGAs	N	WCE	IMH	UPE	PHR	YGI	GP	RIM	CCD	SFS	PE	MT	EES
Aniocha North	7	1.71	1.83	2.00	1.83	1.83	1.29	2.43	1.71	1.80	1.33	1.43	1.57
Aniocha South	3	1.67	2.33	2.00	2.00	2.33	1.33	1.67	2.67	2.00	1.00	1.67	2.00
Burutu	3	1.00	1.50	1.33	1.33	2.00	1.67	2.00	1.67	1.33	1.00	1.67	2.00
Ethiope East	31	1.43	1.93	1.88	1.53	1.59	1.52	2.21	2.15	1.76	1.10	1.82	1.76
Ethiope West	4	1.50	1.50	2.00	1.67	1.75	1.75	2.25	2.00	2.00	2.25	2.25	1.75
Ika North-East	7	1.57	2.14	1.50	1.57	2.00	1.33	2.00	2.29	2.29	1.67	1.43	2.00
Ika South	4	1.50	1.75	2.00	1.67	2.00	1.50	2.25	2.33	2.00	1.00	1.50	2.00
Isoko North	5	1.80	2.00	2.20	1.80	1.20	2.00	2.60	2.40	2.25	1.50	2.00	1.60
Isoko South	2	2.00	1.00	1.00	2.00	2.00	2.00	1.50	1.00	1.50	1.50	1.50	1.50
Ndokwa East	1	2.00	2.00	1.00	2.00	1.00	1.00	2.00	2.00	1.00	1.00	2.00	2.00
Ndokwa West	3	1.33	1.67	2.00	2.00	1.67	1.67	2.67	2.33	2.00	1.33	1.67	2.00
Okpe	5	2.00	1.40	1.60	1.50	1.60	1.50	1.75	1.80	2.00	1.40	2.00	2.00
Oshimili North	4	1.75	1.50	2.00	1.25	1.50	1.50	1.75	1.75	2.00	1.00	2.25	2.00
Udu	4	1.67	2.00	1.67	1.50	2.00	1.67	2.00	2.00	1.50	1.50	1.25	1.25
Ughelli North	4	1.50	2.00	2.50	1.75	1.75	2.00	2.25	2.00	2.25	1.50	1.75	1.75
Ughelli South	6	2.00	2.00	2.17	1.40	1.83	1.40	2.00	1.67	1.83	1.50	1.83	1.50
Ukwani	2	1.00	2.00	1.00	1.00	1.50	1.00	2.00	1.00	1.50	1.00	1.00	1.50
Uvwie	2	1.00	2.00	1.50	1.50	1.00	1.50	2.00	2.00	1.50	1.00	1.50	1.00
Warri South-West	2	2.00	3.00	1.50	1.50	1.50	2.50	2.00	2.50	2.00	2.00	2.00	1.50
Warri South	1	2.00	3.00	3.00	2.00	2.00	2.00	3.00	2.00	3.00	1.00	2.00	2.00

7.2.4 Non-parametric statistical analysis

A major obstacle encountered during the questionnaire survey, was the fact that the study area falls within the crisis prone region of the country. This restricted the areas that could be accessed without risk to the researcher. A way to overcome such problem was to approach host community members living outside the crisis region. Responses were thus collected from community members living within and outside the host communities. The non-parametric Mann-Whitney (independent) and Wilcoxon (paired) tests which are equivalents of the parametric t-test were then applied to compare the responses from the two different groups. These tests do not assume a normal distribution therefore descriptive statistics such as median and range are used to compare the results of the two groups as shown in Table 7.7.

Table 7.7: Descriptive statistics for actual and virtual stakeholders from Isoko host communities (less than 21-45 age range)

	Group 1 - Actual (Stakeholders resident in host community) (N=7)				Group 2 - Virtual (Stakeholders resident outside host community (N=11)			
	Median	Range	Min	Max	Median	Range	Min	Max
WCE	1	2	1	3	2	1	1	2
IMH	2	2	1	3	2	1	1	2
UPE	1	1	1	2	2	1	2	3
PHR	1	1	1	2	2	1	1	2
YGI	1	2	1	3	1	1	1	2
GP	1	1	1	2	2	1	1	2
RIM	2	2	1	3	2	1	2	3
CCD	1	1	1	2	2	1	2	3
SFS	1	1	1	2	2	2	1	3
PE	1	0	1	1	1	2	1	3
MT	2	2	1	3	2	1	1	2
EES	1	2	1	3	2	1	1	2

Table 7.8 displays the results of the non-parametric tests performed on host community members within the age bracket of 21-45. The stakeholders that were resident outside the community were students for the State University and are referred to as virtual as compared to those residing within the community.

Table 7.8: Mann-Whitney Test Statistics(b) for less than 21-45 age groups from Isoko LGA

	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)	Exact Sig. [2*(1-tailed Sig.)a]
WCE	16	44	**-2.08**	0.037	0.07
IMH	29	84	-0.79	0.429	0.601
UPE	20.5	48.5	-1.63	0.103	0.161
PHR	12	40	**-2.59**	0.01	0.025
YGI	32.5	87.5	-0.27	0.786	0.813
GP	13.5	41.5	**-2.53**	0.011	0.033
RIM	32	60	-0.32	0.752	0.813
CCD	17.5	45.5	-1.85	0.064	0.088
SFS	19	47	-1.74	0.083	0.133
PE	21	49	-1.84	0.066	0.193
MT	30	85	0	1	1
EES	29	57	-0.66	0.509	0.601

a Not corrected for ties.

b Grouping Variable: Sampling (Group 1 = Actual, Group 2 = Virtual)

From the Mann-Whitney Test statistics for 21-45 age group, there was significant difference from both groups (that is those living within and outside the host community) at $p<0.05$ for scores assigned to Wealth creation and employment (WCE), Poverty and hunger reduction (PHR) and Global partnership (GP). The other criteria did not show any significance difference. The implication of the results to its utilization in the MCDS framework would be the weights that are assigned to the three sub-criteria. The weights have to be used with caution if they contribute significantly to the cumulative adaptive capacity (AC) value.

7.2.5 Multi-criteria analysis (MCA)

MCA was applied in accordance with the procedure outlined by van Herwijnen and Janssen (2006), and it involves three elements; namely standardization, weighting, and evaluation of alternatives.

7.2.5.1 Standardization of criteria

Potential impact assessment

The criteria for PIA were measured on different measurement units as shown in Table 7.1, therefore they had to be standardized to the same scale. The standardization process was executed using the ILWIS GIS software package (E.C. Inc. 1995). Standardization procedures are slightly different for constraints and factors. Figure 7.8 show the standardized output values for constraints which are Boolean of either 0 (false) or 1 (true).

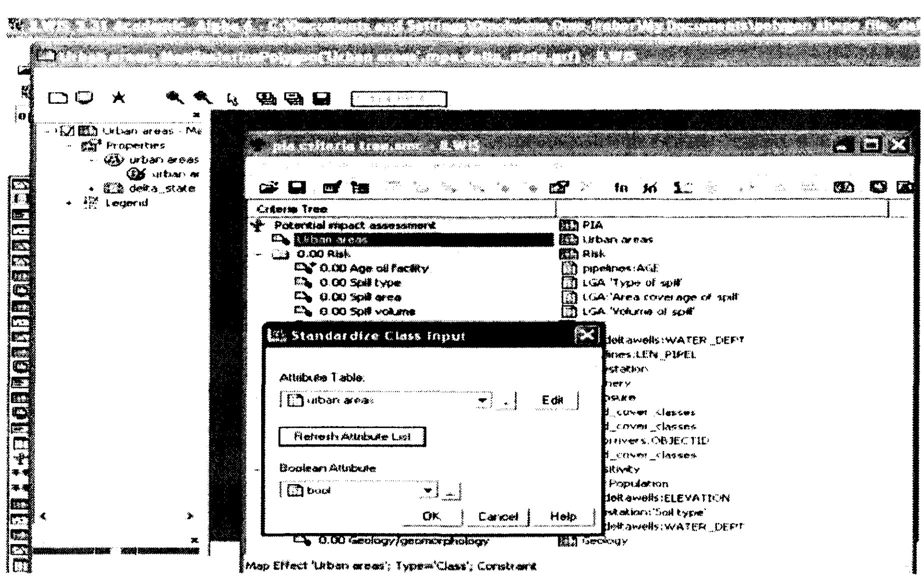

Figure 7.8: Standardized output for constraints using Boolean logic

Standardized value for factors range between 0 and 1, such that low or poor performance of one criterion can be compensated by good performance in another criterion.

The distance map was first created from available data of oil facilities as shown in Figure 7.9. These included oil wells, pipelines, flowstations and refinery.

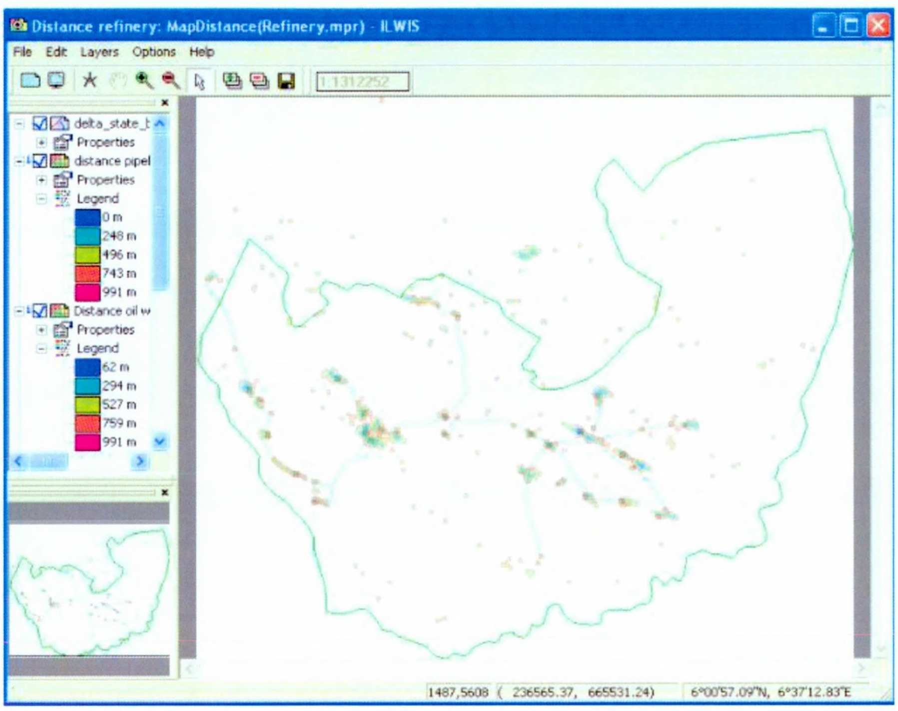

Figure 7.9: Distance map of oil facilities

This was then followed by the standardization of the sub-criteria using the raw scores displayed in Table 7.2. Depending on the type of class the combination method (Figure 7.10) or direct method (Figure7.11) was applied. The combination method was used when dealing with a range of values. For example, the age of oil pipelines varied from 0-42 years. Pipelines less than 5 years old were considered to be of good quality, hence they were standardized to 0, those from 5 to 10 years had increased risk with age, while above 10 were assigned a value of 1 as shown in Figure 7.10.

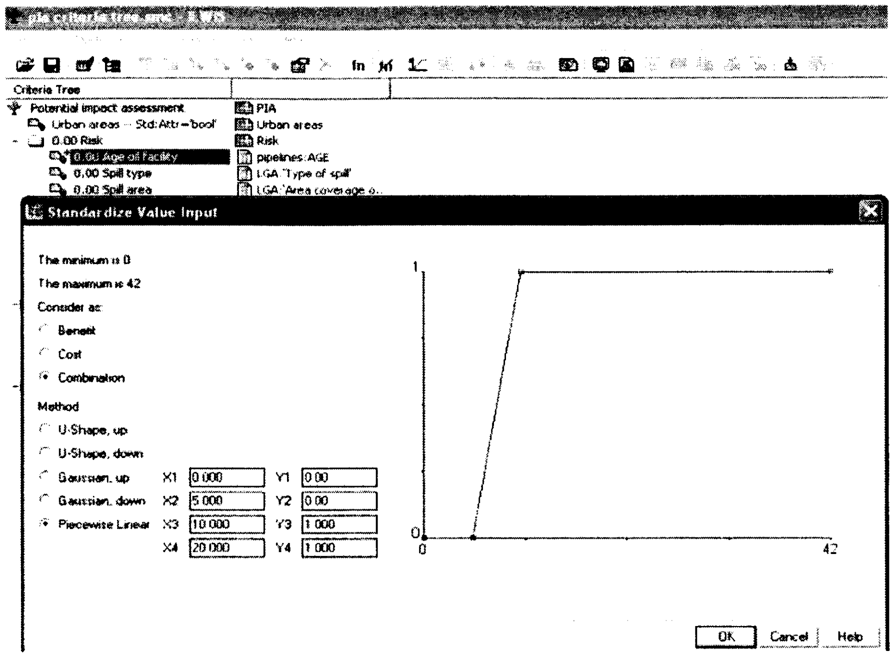

Figure 7.10: Standardization using the combination method

The direct method was applied to criteria that had qualitative information as presented in Figure 7.11. This included for instance the spill type. The risk each posed increased with their volatility.

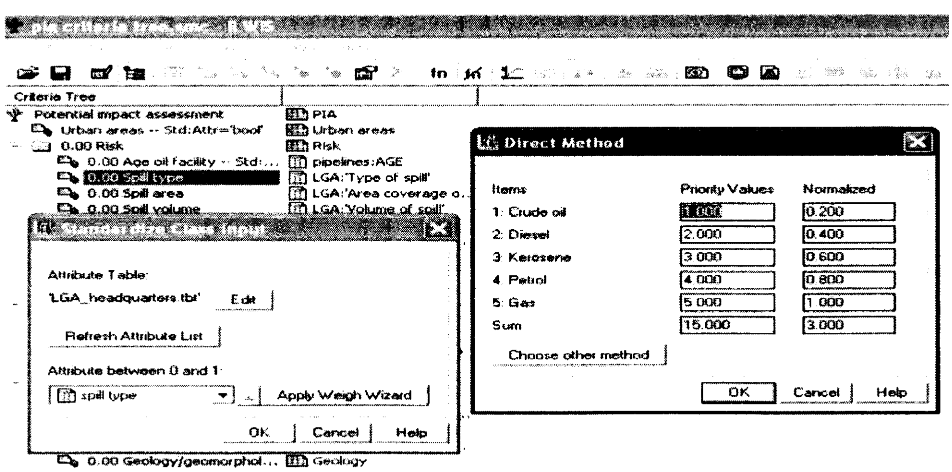

Figure 7.11: Standardization using the direct method

The topographical maps obtained from the Federal Survey did not have contour lines for the extraction of slope. Therefore, satellite data in the form of the US Shuttle Radar Topography Mission (SRTM) was used for the derivation of topographical information as displayed in Figure 7.12. Although topographical information extracted had reduced accuracy as a result of its resolution, it was able to serve the purpose of providing the required data. Due to the limitations of ILWIS GIS package in processing the STRTM data, ENVI GIS software was then used for further analysis with the methodology developed by Qaid et al. (2008).

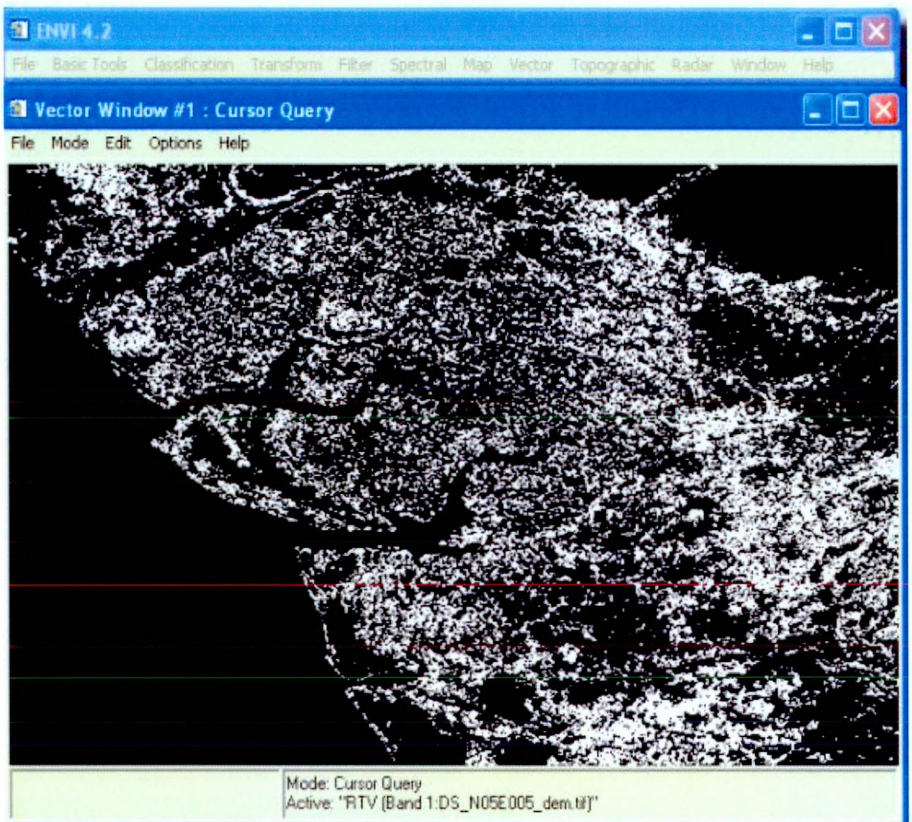

Figure 7.12: Topographical information extracted from SRTM image for parts of Niger Delta

Figure 7.13 shows the final results which were then imported into ILWIS and smoothened with a filter to improve the visualization effect.

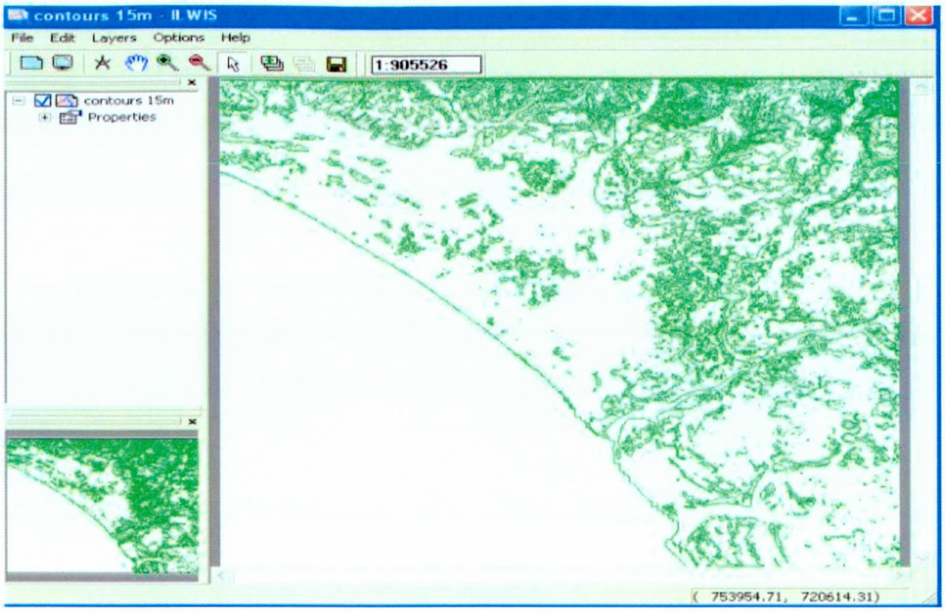

Figure 7.13: Topographical information with 15m contour for parts of the Niger Delta

The slope map was geo-referenced and rasterized to make it compatible with the other data formats. Height calculation differences in x and y - directions, was achieved through filter operations. The resulting maps were saved as *dx* and *dy* respectively. The slope map was then calculated using the map calculation function (MapCalc) in ILWIS as

$$Slope = \left(\left(HYP(dx, dy)/\,pixsize(DEM)\right) * 100\right) \qquad (7.1)$$

where *HYP* is the hypotenuse, *pixsize (DEM)* is the pixel size of the raterized slope map which in this case is 30m..

Adaptive capacity

Due to lack of previously collated socio-economic data for the study area, the adaptive capacity criteria were obtained by questionnaire survey as described in section 7.2.1.2. Each criterion ranging from 1-3 was standardized using the procedure explained in section 4.4.4.3. The standardized scores are displayed in Table 7.9.

Table 7.9: Standardized scores for adaptive capacity criteria

AC LGAs	N	WCE	IMH	UPE	PHR	YGI	GP	RIM	CCD	SFS	PE	MT	EES
Aniocha North	7	0.43	0.39	0.33	0.39	0.39	0.57	0.19	0.43	0.40	0.56	0.52	0.48
Aniocha South	3	0.44	0.22	0.33	0.33	0.22	0.56	0.44	0.11	0.33	0.67	0.44	0.33
Burutu	3	0.67	0.50	0.56	0.56	0.33	0.44	0.33	0.44	0.56	0.67	0.44	0.33
Ethiope East	31	0.52	0.36	0.37	0.49	0.47	0.49	0.26	0.28	0.41	0.63	0.39	0.41
Ethiope West	4	0.50	0.50	0.33	0.44	0.42	0.42	0.25	0.33	0.33	0.25	0.25	0.42
Ika North-East	7	0.48	0.29	0.50	0.48	0.33	0.56	0.33	0.24	0.24	0.44	0.52	0.33
Ika South	4	0.50	0.42	0.33	0.44	0.33	0.50	0.25	0.22	0.33	0.67	0.50	0.33
Isoko North	5	0.40	0.33	0.27	0.40	0.60	0.33	0.13	0.20	0.25	0.50	0.33	0.47
Isoko South	2	0.33	0.67	0.67	0.33	0.33	0.33	0.50	0.67	0.50	0.50	0.50	0.50
Ndokwa East	1	0.33	0.33	0.67	0.33	0.67	0.67	0.33	0.33	0.67	0.67	0.33	0.33
Ndokwa West	3	0.56	0.44	0.33	0.33	0.44	0.44	0.11	0.22	0.33	0.56	0.44	0.33
Okpe	5	0.33	0.53	0.47	0.50	0.47	0.50	0.42	0.40	0.33	0.53	0.33	0.33
Oshimili North	4	0.42	0.50	0.33	0.58	0.50	0.50	0.42	0.42	0.33	0.67	0.25	0.33
Udu	4	0.44	0.33	0.44	0.50	0.33	0.44	0.33	0.33	0.50	0.50	0.58	0.58
Ughelli North	4	0.50	0.33	0.17	0.42	0.42	0.33	0.25	0.33	0.25	0.50	0.42	0.42
Ughelli South	6	0.33	0.33	0.28	0.53	0.39	0.53	0.33	0.44	0.39	0.50	0.39	0.50
Ukwani	2	0.67	0.33	0.67	0.67	0.50	0.67	0.33	0.67	0.50	0.67	0.67	0.50
Uvwie	2	0.67	0.33	0.50	0.50	0.67	0.50	0.33	0.33	0.50	0.67	0.50	0.67
Warri South-West	2	0.33	0.00	0.50	0.50	0.50	0.17	0.33	0.17	0.33	0.33	0.33	0.50
Warri South	1	0.33	0.00	0.00	0.33	0.33	0.33	0.00	0.33	0.00	0.67	0.33	0.33

7.2.5.2 Normalization of weights

Weighting of the criteria was achieved by experts on the basis of their generally accepted knowledge.

Potential impact assessment

For the normalization of PIA criteria, SMCE was used. The weights were then normalized such that they sum up to 1. The normalised weights for the main criteria are presented in Figure 7.14

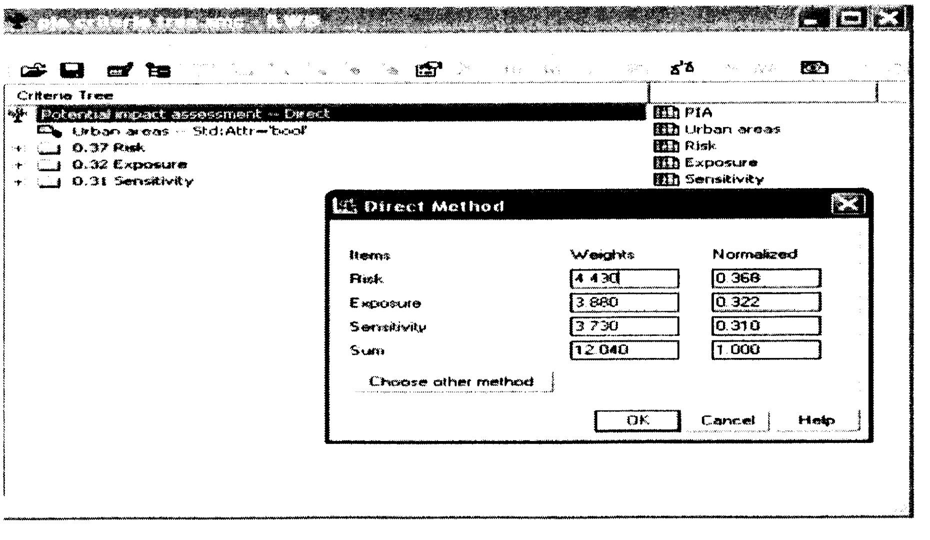

Figure 7.14: Normalized weights for potential impact assessment main criteria

The normalized weights for the sub-criteria are shown in Figure 7.15.

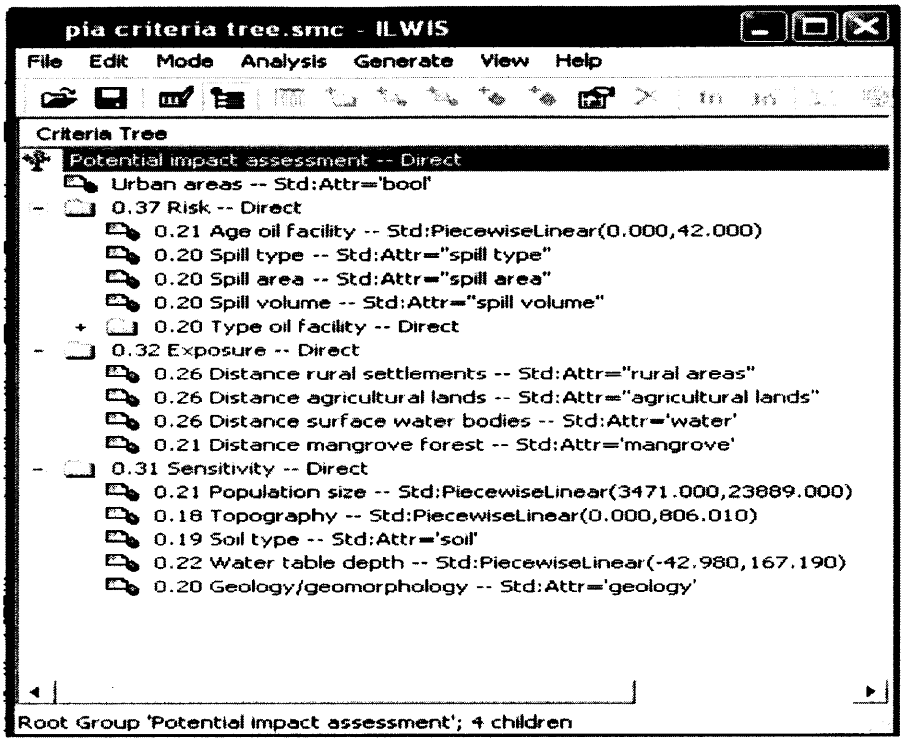

Figure 7.15: Normalized weights for potential impact assessment sub-criteria

Adaptive capacity

The normalization of AC was executed using Microsoft Excel. The derived values are shown in Table 7.10.

Table 7.10: Normalized weights for Adaptive capacity

Criteria	Code	Actual weight
Wealth creation and Employment	WCE	0.093
Improved maternal health	IMH	0.083
Universal primary education	UPE	0.089
Poverty and hunger reduction	PHR	0.096
Youth/gender issue	YGI	0.076
Global partnership for development	GPD	0.078
Reduction in infant mortality	RIM	0.083
Combating common diseases	CCD	0.083
Shelter and food security	SFS	0.088
Power and energy	PE	0.086
Mass transportation	MT	0.063
Ensure environmental sustainability	EES	0.082

As pointed out in section 7.2.4, the weights calculated for WCE, PHR were high in comparison with other weights, therefore the results have to be used with caution, implying the need for verification with actual stakeholders residing within the host communities.

7.2.5.3 Aggregation of alternatives

The Weighted summation method (WSM) (discussed in section 4.4.2.4) was applied for the evaluation of criteria. The overall human vulnerability index (HVI) was obtained as explained in section 3.5.1.1 and was calculated using

$$Vulnerability = f\left[Potential\ Impact, Adaptive\ Capacity\right] \qquad (7.2)$$

Where potential impact was determined by

$$PI = \sum_{i=1}^{n} w_i x_i \prod_{j=1}^{m} c_j \qquad (7.3)$$

where PI is the potential impact index, w_i is the weight of factor i, x_i is criterion score of factor i, n is the number of factors, c_j, is the criterion score (1 or 0) of constraints j and m is the number of constraints. In other words, Boolean images are created to represent each constraint, where the Boolean image has a value 1 for reclassified cells that satisfies the constraint and 0 otherwise. By "modelling" these Boolean images representing the constraints, only those cells that satisfy all constraints (non-zero) will be considered in the allocation. Those cells that have at least one zero value (because of at least one constraint not being satisfied), will have a zero multiplicative value, and hence, it is assigned a zero suitability (Mendoza, 1997), or as in this study zero vulnerability.

This information was calculated spatially with PIA values ranging from 0-1. Results of PIA for the Local Government Areas assessed are displayed in Figure 7.16.

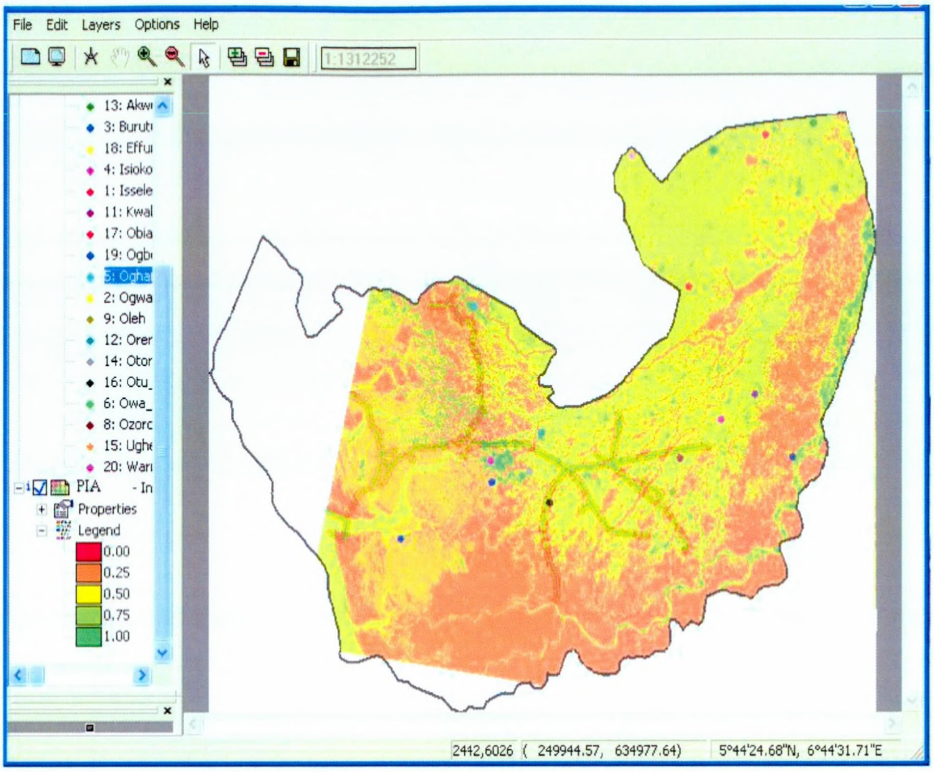

Figure 7.16: Aggregated spatial information for estimation of potential impact assessment

The adaptive capacity (AC) was calculated using Equation 7.4.

$$AC = \sum_{i=1}^{n} w_i x_i \tag{7.4}$$

Table 7.11 displays the PIA and AC values for the LGAs investigated, while the resulting vulnerability of inhabitant as a result of their close proximity to oil production and transportation facilities is shown in Figure 7.17.

Table 7.11: Calculated potential impact assessment (PIA) and adaptive capacity (AC) values for Local Government Areas (LGAs) in Delta State

S/N	LGAs	Headquarters	PIA	AC
1	Aniocha North	Issele-Uku	0.80	0.42
2	Aniocha South	Ogwashi-Uku	0.80	0.37
3	Burutu	Burutu	0.20	0.49
4	Ethiope East	Isiokolo	0.60	0.43
5	Ethiope West	Oghara	0.90	0.37
6	Ika North-East	Owa Oyibo	0.80	0.39
7	Ika South	Agbor	0.60	0.40
8	Isoko North	Ozoro	0.60	0.35
9	Isoko South	Oleh	0.60	0.49
10	Ndokwa East	Aboh	0.20	0.47
11	Ndokwa West	Kwale	0.80	0.38
12	Okpe	Orerokpe	0.60	0.43
13	Oshimili North	Akwukwu-Igbo	0.60	0.44
14	Udu	Asaba	1.00	0.44
15	Ughelli North	Ughelli	1.00	0.36
16	Ughelli South	Otu-Jeremi	0.30	0.41
17	Ukwani	Obiaruku	0.50	0.57
18	Uvwie	Effurun	0.90	0.51
19	Warri South-West	Ogbe-Ijoh	0.20	0.34
20	Warri South	Warri	1.00	0.25

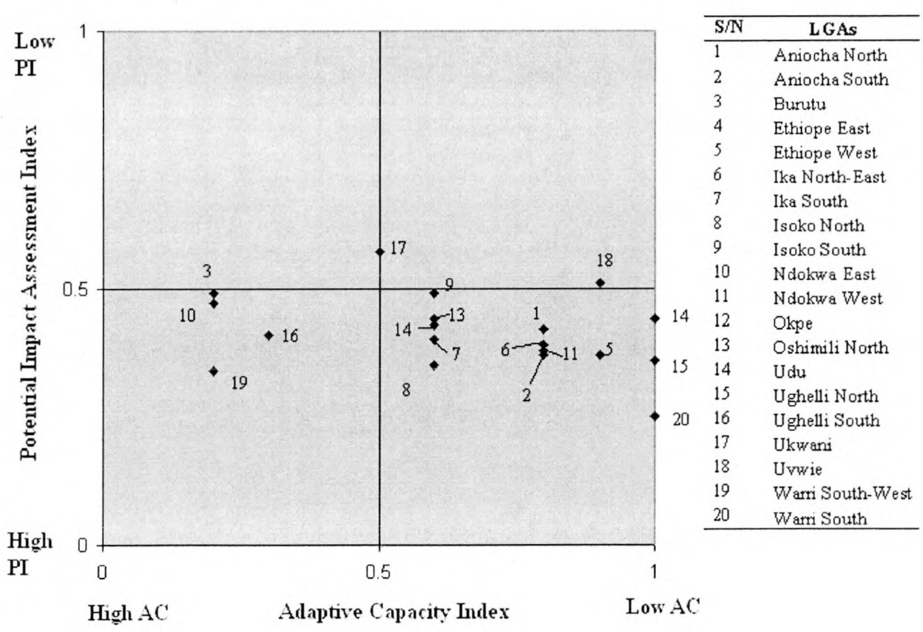

Figure 7.17: Vulnerability of inhabitants of an oil producing region (Delta State)

The results show that majority of the investigated areas fell within the region requiring rehabilitation and none fell in the 'do nothing' region. Care must be taken when using the above information as the participants who took part in criteria scoring of AC were resident outside the communities (refer to section 7.2.4).

7.3 Groundwater Vulnerability Assessment

Groundwater is treated in this section as a target as compared to Chapter 6 where it was approached from the viewpoint of a pathway. In assessing its vulnerability, the DRASTIC model as discussed in section 3.5.1.2 was applied. The major emphasis is the weighing of the criteria by experts in the field of Geology. Students and lecturers were involved in the weighting of the DRASTIC factors. Weights obtained are an essential aspect for the prioritization of contaminated sites as applied in section 8.2.1.

7.3.1 Vulnerability assessment using DRASTIC model

Vulnerability assessment using DRASTIC model can be derived from parameters listed in Table 7.12.

Table 7.12: Parameters for groundwater vulnerability assessment

Data set	Parameters	Source of information
Geological map	Geological units	Geological survey
Topographical map	Slope	SRTM
Hydrological data	Recharge	Literature
Piezometric level map	Depth to water table	SPDC
Hydraulic conductivity map	Hydraulic conductivity	SPDC

The estimation of recharge was based on data obtained from available literature. Annual precipitation of 2,800 mm (Niger Delta Environmental Survey, 1997) and evapo-transpiration rate of 1000mm ((Oladipo, 1980) were used for the estimation. Recharge is the difference between precipitation and evapo-transpiration. For each of the factors, weights (relative importance) were elicited from experts (in this case students and lecturers in the Department of Geology) ranging from 1 - 5, where 1 = least important and 5 = most important as already mentioned in section 4.4.2. The grouped median of the derived weights are shown in Table 7.13 and Figure 7.17.

Table 7.13: Relative importance (weights) for groundwater vulnerability assessment based on expert knowledge (students versus lecturers)

	Depth of water	Net recharge	Aquifer media	Soil media	Slope	Impact of vadose zone	Hydraulic conductivity of aquifer
Students	4.26	3.44	4.19	3.64	3.75	4.00	4.13
Lecturers	4.00	3.60	3.57	3.33	2.75	3.00	3.75
Total	**4.21**	**3.48**	**4.00**	**3.55**	**3.50**	**3.74**	**4.05**
SE	**0.162**	**0.182**	**0.175**	**0.176**	**0.213**	**0.205**	**0.175**

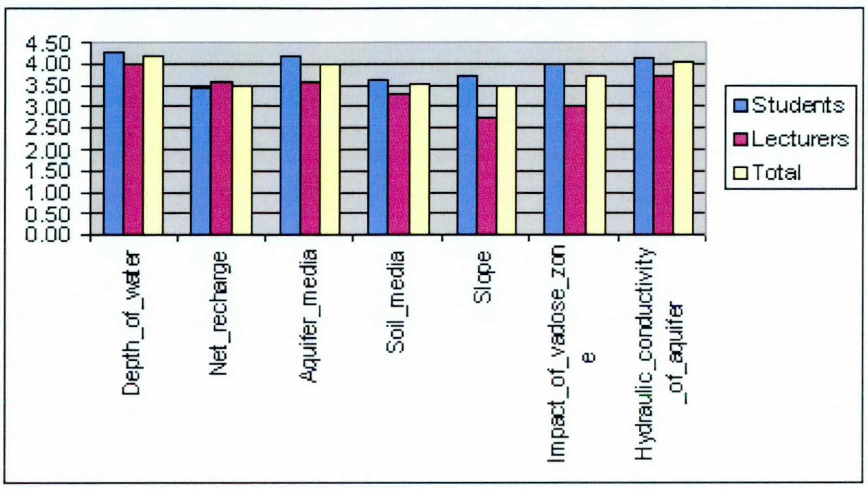

Figure 7.18: Relative importance (weights) for groundwater vulnerability assessment based on expert knowledge (students versus lecturers)

The results show a general consistency in the weights assigned to Depth of water, Net recharge, Soil media and Hydraulic conductivity of aquifer, while Aquifer media, Slope, Impact of vadose zone exhibited high inconsistencies between the two groups of experts.

7.4 Mangrove Vulnerability Assessment

In order to develop a method for the assessment of mangrove vulnerability, establishing the factors responsible for mangrove survival is an essential component. Eleven different input parameters are required in modelling mangrove vulnerability. These parameters and their effects on mangrove vulnerability were selected and weighed by experts. Criteria identification and selection were mainly based on effects of environmental and socio-economic changes associated with mangrove survival.

Experts made up of lecturers in the fields of environment such as geology, microbiology and chemistry were involved in the identification of criteria for mangrove vulnerability and weighing of the criteria. The weights ranged from 1 - 5, where 1 = least important and 5 = most important, as already mentioned in section 4.4.2.

7.4.1 Identification and selection of criteria

The ability of mangrove ecosystems to adapt to environmental changes depends largely upon environmental and socio-economic factors (see Table 7.14).

Table 7.14: Criteria and sub-criteria for mangrove vulnerability assessment

Criteria	Sub-criteria	Description	Data sources
Environmental	**Carbon dioxide**	The CO_2 content of the atmosphere is usually expressed in parts per million (ppm) by weight and the use of fossil fuels is expressed as so many tons of carbon burned per year. CO_2 in the atmosphere can be estimated from the amount released from fossil fuel burning. The burning of fossil fuels presently releases 7 billion tons of carbon into the atmosphere each year, on a global scale, in the form of carbon dioxide gas, CO_2. Presently, the mangroves, like other forest zones, are sinks to the excess CO_2 emitted. They act as buffer protecting the environment from the full effect of global warming.	Relevant data can be obtained from the United States NASA website http://data.giss.nasa.gov/co2_fung/
	Relative humidity	Water vapour is the most important heat-trapping greenhouse gas in our atmosphere. Specific humidity refers to the actual amount of water vapour in the air. Relative humidity relates to the saturation point, the amount of water vapour in the air divided by the maximum amount of water the air is capable of holding at a given temperature. As air temperatures rise, warm air can hold more water, and the saturation point of the air also increases.	Meteorological station
	Temperature	Mangrove species usually occur where annual temperature is high and temperature amplitude is small. Seasonal temperature changes of less than 10°C are favourable for good growth. The ideal temperature for photosynthesis is 35°C. Low temperature reduces the tree size, leaf area index and species composition of the flora as well as the complexity of communities. Typically, mangroves occur in areas where mean annual temperatures do not drop below 19°C (66°F) (Waisel, 1972). Short-term extreme temperatures of 4°C to 60°C can be tolerated but these should never suddenly arise,	Meteorological station

Criteria	Sub-criteria	Description	Data sources
		but rather increase or decrease slowly.	
	Sea-level rise	Regional sea-level rise is affected by tectonic movements that can cause land subsidence or uplift. Natural and human induced sediment compaction can also exacerbate the impacts of sea-level rise. Humans contribute to land subsidence through coastal development that causes deficits in the sediment budget, shipping channels that cause bank erosion, groundwater or oil extraction that causes submergence, and dredging and mining that causes losses of land (McLeod and Salm, 2006). Global mean sea level is projected to rise 9 to 88 cm between 1990 and 2100 (Gilman et al., 2006). Estimates can be used to assess site-specific mangrove vulnerability to projected sea level rise.	High to medium resolution satellite images
	Precipitation	Changes in precipitation patterns caused by climate change may have a profound effect on both the growth of mangroves and their areal extent (Field 1995; Snedaker 1995). Mangrove areas experiencing increased rainfall will experience an increase in area, with mangrove colonization of previously non-vegetated areas of the landward fringe, and there will be an increase in diversity of mangrove zones and growth rates (Ellison, 2000).	Meteorological Station
	Alien invasive species	A major anthropogenic factor contributing to the degradation and depletion of the mangroves is the invasion of the non-native Nypa palm (Nypa *fruticans*). The Nypa palm was first introduced in Calabar in 1906 and later in Oron in 1912. The species rapidly established itself successfully and in the process displaced the native mangrove vegetation (CEDA, 1997). Unfortunately, it failed to play the role of erosion control for which it was introduced to Nigeria; rather it has helped to reduce the firmness of the coastal sediments. Other problems caused by the presence of the invasive	-

Criteria	Sub-criteria	Description	Data sources
		palm include the general habitat conversion with attendant reduction in fish catch, poor navigation, ecological degradation and loss of biodiversity	
	Pollutant input	Important parameters are required for monitoring pollution level in coastal regions where mangrove strives. A wide variety of pollutants affects the world's mangrove. Pollutants include nutrients, pathogens, persistent organic pollutants and heavy metals, oil, and solid waste (Burke et al., 2001). Of particular interest are petroleum residues which can contaminate marine and coastal waters through various routes: accidental oil spills from tankers, pipelines, and exploration sites; regular shipping and exploration operations, such as exchange of ballast water; runoff from land; and municipal and industrial wastes (Burke et al., 2001). Heavy metals also pose a threat to the survival of mangrove and those that are commonly monitored include cadmium, copper, mercury, lead, nickel, and zinc.	Field survey
Socio-economic	**Population pressure**	Industrialization coupled with urban and rural settlements impose a high demand for land. Therefore human population pressure is increasingly a contributory factor in the loss of the mangrove habitat globally.	Census data
	Deforestation	High rates of deforestation in mangroves can be linked mainly to agricultural activities. The crucial point is that the deforestation of mangrove is largely attributed to changing socio-economic conditions	High to medium resolution satellite data
	Poverty	Poverty in the local populations often results from a destabilization of their social context and a resulting break in the provision of their traditional resources (Diop, 2003).	http://www.ruralpovertyportal.org/english/regions/africa/nga/index.htm and by interview

The grouped median of the derived weights are shown in Table 7.15 and Figure 7.19.

Table 7.15: Relative importance (weights) for mangrove vulnerability assessment based on expert knowledge (lecturers from different disciplines)

	Population pressure	Deforestation	Civil conflicts	Poverty	Carbon dioxide	Relative humidity	Temperature	Sea level rise	Precipitation	Alien invasive species	Pollutant input
Geology	3.57	3.60	3.38	3.50	3.17	2.50	3.00	2.40	3.17	3.50	4.00
Microbiology	3.67	4.00	3.00	4.33	3.50	3.25	4.00	4.00	3.00	2.00	4.00
Chemistry	3.33	3.75	3.00	3.60	3.00	3.00	3.00	3.25	4.33	3.33	4.00
Total	**3.55**	**3.73**	**3.21**	**3.69**	**3.11**	**2.80**	**3.25**	**3.18**	**3.27**	**3.10**	**4.00**
SE	**0.24**	**0.24**	**0.21**	**0.20**	**0.28**	**0.15**	**0.22**	**0.25**	**0.34**	**0.27**	**0.27**

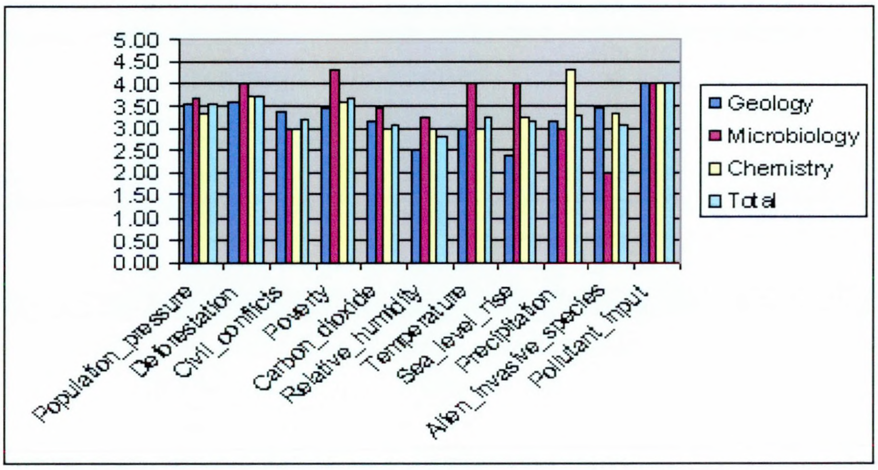

Figure 7.19: Relative importance (weights) for mangrove vulnerability assessment based on expert knowledge (lecturers from different disciplines)

7.5 Summary

The MCDS framework has been applied for the vulnerability assessment of targets, as a result of the close proximity of targets to oil production and transportation facilities. The framework made use of spatial information derived from landcover maps as mentioned in Chapter 5. GIS techniques provided the structure for the combination of different sources of information. MCA was used to integrate weights obtained from experts. This adds to the credibility and transparency of the decision process

Chapter 8 : Application of MCDS Framework for Prioritising Contaminated/Degraded Sites

8.1 Introduction

The need for a MCDS framework for prioritising contaminated/degraded sites has been discussed extensively in section 1.4. The framework developed also not only takes into consideration the immediate effect of contamination, but also looks at the environmental, social and economic impact arising from such spill incident. The evaluation of the MCDS framework using four known spills site is executed. It must be stated that due to the difficulty in assessing recent spill sites, the researcher made use of sites where spills occurred between 2002 and 2003 as shown in Table 4.2. Such a framework is expected to provide a transparent and credible decision support aid to parties involved in the decision process and to those affected by the decision outcome.

8.2 Problem Definition

The overall objective or goal is to prioritize contaminated/degraded areas as a result of oil operations. As discussed in the design phase in section 4.4.3.2, a hierarchy tree has to be established with the objective, sets of criteria/sub-criteria and alternatives as illustrated in Figure 8.1. The alternatives were selected from four sites located in Delta State.

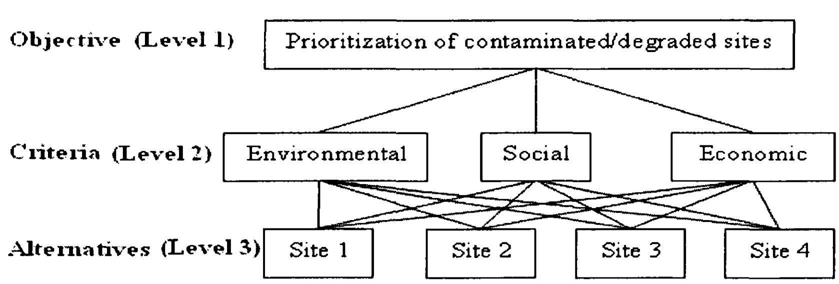

Figure 8.1: Hierarchy structure of objectives, criteria and alternatives

The choice of decision criteria is a necessary step in MCA. Criteria used in the study were grouped into three main categories – environmental, social and economic. The main criteria were divided into sub-criteria for additional information and for clarification and refinement (Qureshi and Harrison, 2003), as presented in Table 8.1

The first level represents the ultimate goal of the decision hierarchy. The second level represents the criteria and sub-criteria utilized in this work and the third level represents the options or alternatives. These alternatives were described by indices and evaluated by means of some specific criteria, which made up the decision rules. Table 8.1 displays the sustainable development criteria that were selected after exhaustive deliberation with relevant expert groups. The criteria were thus found to be satisfactorily flexible and dynamic for addressing the current problem at hand. The data derived from these criteria were then stored in a database.

Data used for the environmental criteria were obtained from various sources (Table 8.1) such as field survey, reports, publications and web sites. Data for social and economic criteria were mainly obtained from questionnaire survey (Appendix C.4)

Table 8.1: Criteria for prioritization of contaminated sites

Main criteria	Sub-criteria	Unit	Data link to other chapters/sources	Site 1	Site 2	Site 3	Site 4
Environmental	Effect on groundwater quality/quantity recharge	Index	Chapters 7	135	162	214	210
	Soil contamination	mg/kg	Field survey	455.0	5.7	2.5	1.7
	Impact on vegetation	Index	Field survey	No	No	No	Yes
	Characteristics of hydrocarbon spill	-	Reports	Crude	Petrol	Crude	Crude
	Land cover land use change	%	Chapter 5	-	-	-	-
	Degradation of surface water quality	Index	Chapter 6	Yes	Yes	No	No
Social	Dislocation of persons	Index	Questionnaire survey	1.88	2.00	1.80	1.75
	Health impact	Index	Questionnaire survey	1.75	1.50	2.00	2.07
	Aesthetic effect	Index	Questionnaire survey	2.29	3.00	2.25	2.60
	Effect on cultural resources	Index	Questionnaire survey	1.75	1.75	2.25	1.50
	Psychological attitude resulting from spill	Index	Questionnaire survey	1.78	1.50	1.80	1.65
	Communal conflict	Index	Questionnaire survey	1.56	2.25	1.80	1.59
Economic	Type of income affected	Index	Questionnaire survey	1.00	2.00	3.00	2.00
	Magnitude of economic loss	Index	Questionnaire survey	1.70	1.00	1.20	1.33
	Effect on sustainable income	Index	Questionnaire survey	1.30	1.50	1.40	1.38
	Effect on property value	Index	Questionnaire survey	1.44	2.00	1.00	1.00
	Intensity of economic activity around spill	Index	Questionnaire survey	1.63	2.00	1.50	1.33

8.3 Multi-Criteria Analysis

8.3.1 Standardization of criteria

The criteria for determination of priority sites were measured on different scales; therefore standardization was necessary in order to obtain meaningful estimate.

8.3.1.1 Environmental criteria

Data sets for environmental criteria were collected from various sources with varying units of measurement as displayed in Table 8.1, hence the apparent need for their standardization.

Effect on groundwater quality/quantity was obtained from groundwater vulnerability assessment as discussed in section 7.3. The ratings were obtained for the four sites from available data listed in Table 7.12 and calculated using Equation 3.14. The calculated values for the four sites are presented in Table 8.2.

Table 8.2: Groundwater vulnerability index for the selected sites

Ratings	D	R	A	S	T	I	C	Index
Site 1	10	10	3	1	10	1	1	135.24
Site 2	7	10	8	3	9	3	3	161.79
Site 3	6	10	8	8	9	8	8	214.28
Site 4	5	10	8	8	9	8	8	210.07
Weights	4.21	3.48	4.00	3.55	3.50	3.74	4.05	

The maximum level decided for the groundwater vulnerability assessment using DRASTIC index was set as 200 in accordance with Secunda et al. (1998). Standardization was determined using the combination method as displayed in Figure 8.2

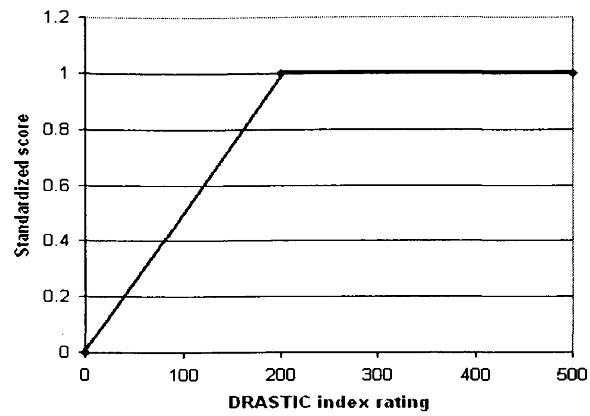

Figure 8.2: Standardization of DRASTIC index rating

Soil samples were collected from the sites to obtain contamination level of affected sites (sections 4.2.2.1 and 6.3.2.3). Results were compared with those collected from control sites. TPH was used as the major constituent for the determination of the level of soil contamination from oil spill. The threshold value for level of soil contamination can be established using two methods – guidelines set by organisations responsible for monitoring standards such as the Dutch intervention standard normally used in EIA studies in Nigeria. Unfortunately this does not have a threshold value for TPH. The second method involved sampling from control sites as discussed in section 6.4.2.3 were used. The maximum value obtained from the control site was 2.4mg/kg. This was then used as the threshold value and standardized as displayed in Figure 8.3.

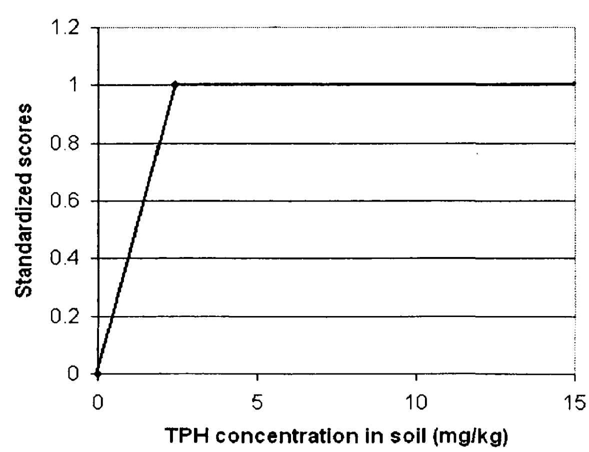

Figure 8.3: Standardization chart for TPH concentration in soil

Impact on vegetation can be determined either by vulnerability assessment as discussed in section 7.4 or by level of contaminant present in the vegetation around the spill site. Due to the lack of data to estimate the impact, a third method was developed. Since mangrove vegetation is the most important in the coastal region, the researcher then applied knowledge from the classified landcover map obtained in Chapter 5 in combination with existing reports to establish the presence of mangrove in the selected sites. The presence of mangrove was assigned 1 for YES and 0 for NO.

The standardization for the characteristics of oil spill was similar to the procedure discussed in section 7.2.5.1, where crude oil was assigned a value of 0.20 and petrol a value of 0.80.

It was not possible to determine the landcover/landuse change due to the quality of materials used in Chapter 5 of this research work. The spatial (30m) and temporal (26 days) resolutions of the satellite images used were not capable of detecting meaningful landcover/landuse changes on oil spill sites. Additionally the most recent image that was found useful for this research was obtained in 2002. Lastly the time lag between the two images used for change detection was large; hence a value of zero was assigned for the four sites.

Standardized values for environmental criteria are presented in Table 8.3.

Table 8.3: Standardized scores for environmental sub-criteria

Sub-criteria	Site 1	Site 2	Site 3	Site 4
Effect on groundwater quality/quantity recharge	0.68	0.81	1.00	1.00
Soil contamination	1.00	1.00	1.00	0.71
Impact on vegetation	1.00	0.00	0.00	0.00
Characteristics of hydrocarbon spill	0.20	0.80	0.20	0.20
Land cover land use change	0.00	0.00	0.00	0.00
Degradation of surface water quality	1.00	1.00	0.00	0.00

From Table 8.3, soil contamination had the highest values ranging from 0.71 - 1.00. The data available for land cover change was inadequate to identify changes resulting from oil spill, so a value of zero was assigned for all sites.

8.3.1.2 Socio-economic criteria

Information on the socio economic status of contaminated sites was obtained from questionnaire survey using rural dwellers from the affected areas. These sets of criteria were easier to standardize because they were collected on the same scale of 1-3. The scores still need to be standardized to make them appear on the same scale as the environmental criteria. Each criterion was then standardized using the procedures explained in sections 4.4.4.3 and 7.2.5.1. The raw scores were standardized using a linear or direct method as shown in Figure 8.4.

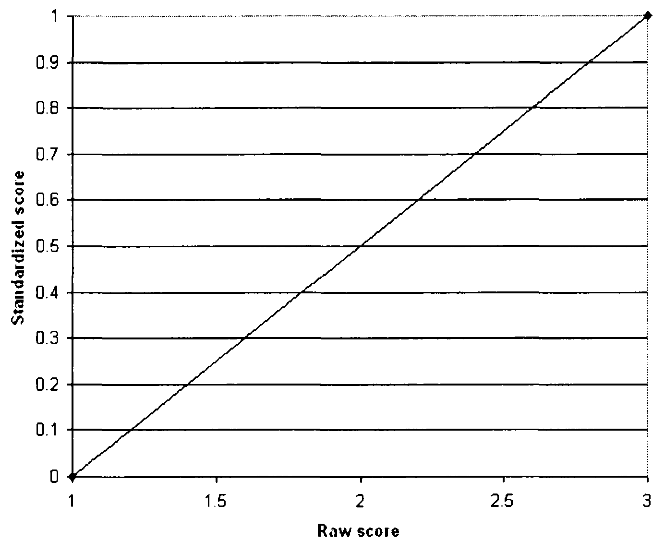

Figure 8.4: Linear standardization of social and economic criteria for prioritization of contaminated sites

The standardized scores for socio-economic criteria are presented in Table 8.4.

Table 8.4: Standardized scores for social and economic criteria

Criteria	Sub-criteria	Site 1	Site 2	Site 3	Site 4
Social	Dislocation of persons	0.62	0.66	0.59	0.58
	Health impact	0.58	0.50	0.66	0.68
	Aesthetic effect	0.76	0.99	0.74	0.86
	Effect on cultural resources	0.58	0.58	0.74	0.50
	Psychological attitude resulting from spill	0.59	0.50	0.59	0.54
	Communal conflict	0.51	0.74	0.59	0.52
Economic	Type of income affected	0.33	0.66	0.99	0.66
	Magnitude of economic loss	0.56	0.33	0.40	0.44
	Effect on sustainable income	0.43	0.50	0.46	0.46
	Effect on property value	0.48	0.66	0.33	0.33
	Intensity of economic activity around spill	0.54	0.66	0.50	0.44

Table 8.4 indicates that social sub-criteria (aesthetic effect) recorded the highest criteria value for sites 1, 2 and 4, with economic sub-criteria (type of income affected) being the highest for site 3. The lowest value of 0.33 was recorded in the economic criteria, implying that participants felt they were more economically than socially disadvantaged.

8.3.2 Normalization of criteria weights

The normalized weights were derived using the following equation

$$z = y_i \Big/ \sum_{i=1}^{n} y_i \qquad (8.1)$$

Where z is the normalized weight value for the ith class, y_i is the raw weight. The normalized weights for the main criteria are shown in Table 8.5 and Figure 8.5.

Table 8.5: Normalized weights obtained from experts in oil related organisations

Main criteria / Experts	Environmental	Social	Economic
Oil Company	0.39	0.24	0.36
DPR	0.41	0.23	0.37
FMEn	0.38	0.30	0.32
Total (All groups)	**0.39**	**0.25**	**0.36**

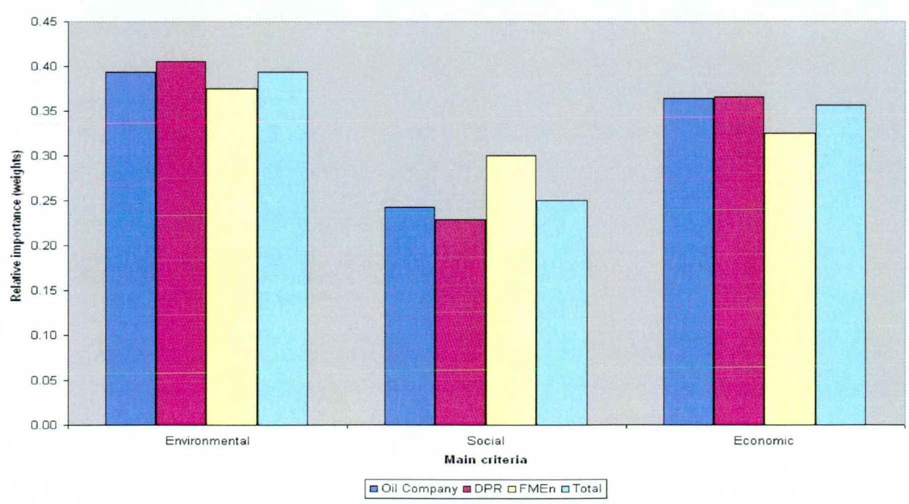

Figure 8.5: Normalized weights of main criteria from experts

Table 8.5 indicate a general agreement by the three groups of experts that the environmental criteria are of more importance than the social and economic criteria. This was followed by the economic criteria, while social criteria were given the least importance.

Two sets of normalized weights were calculated for the identified sub-criteria. The first was using the weights generated from the main criteria as shown in Figure 8.6 (a), the second was normalizing the average weights of all the experts as presented in Figure 8.6(b).

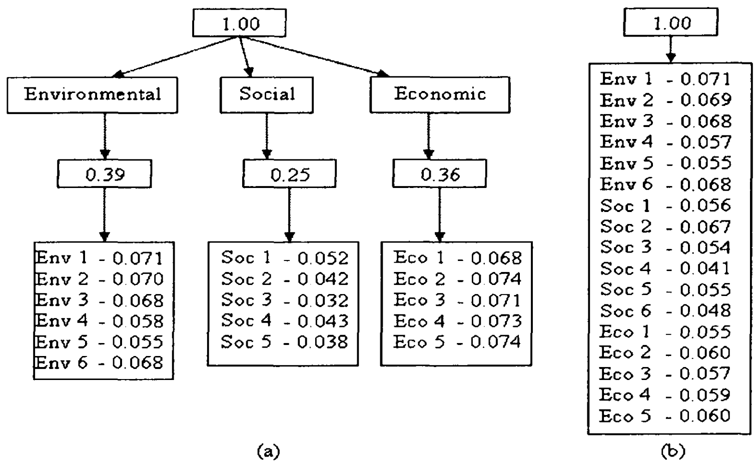

Figure 8.6: Normalized weights for sub-criteria using (a) weights derived from main criteria (b) average weights from experts

The normalized weights for environmental criteria are quite close when the two weighting methods were applied. Social criteria experienced an increase from weights derived from average weights from experts in comparison to those obtained using the weights derived from main criteria. Economic criteria on the other hand experienced a general decrease in weighted values. The values obtained were tested were further utilized in sensitivity analysis in section 8.4.1.

The normalized weights for all experts for the methods are displayed in Figures 8.7 and 8.8 respectively.

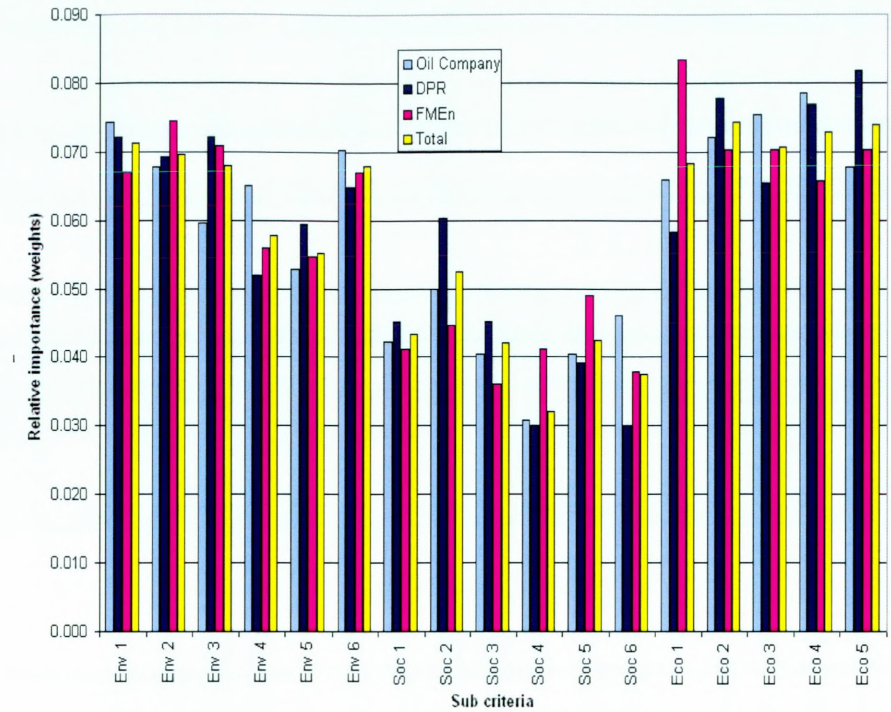

Figure 8.7: Normalized weights of sub-criteria using calculated weights from main criteria.

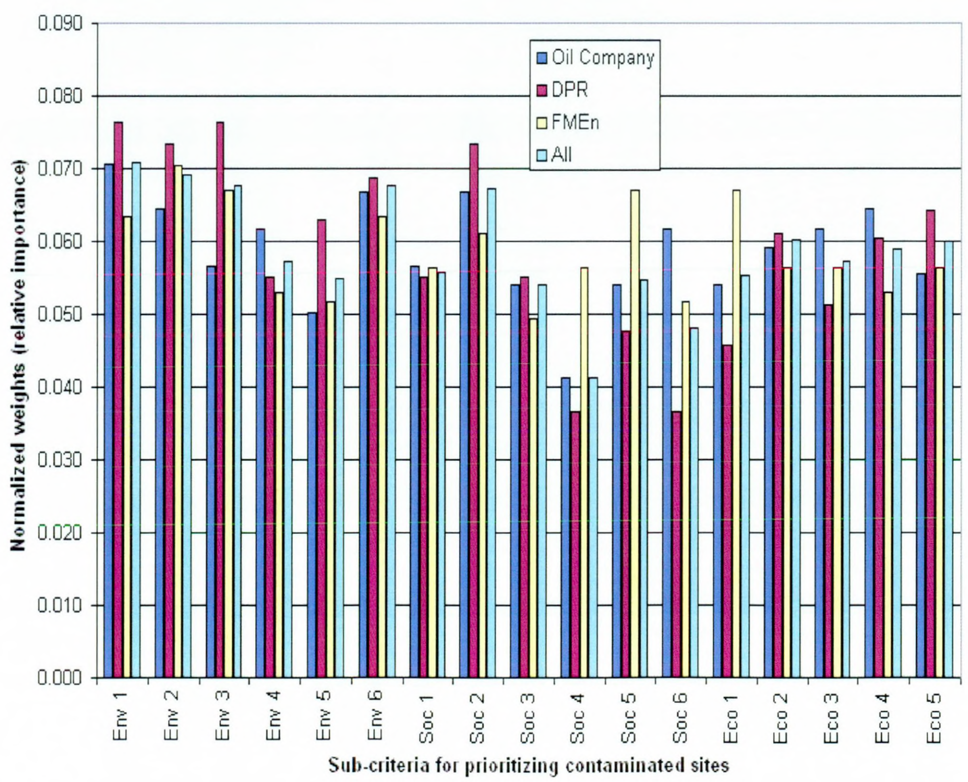

Figure 8.8: Normalized weights of sub-criteria using equal weighting

Figure 8.7 shows a pronounced increase in economic criteria. This is attributed to the lower number of sub-criteria in the group. In Figure 8.8, environmental criteria generally had higher values with effect on groundwater quality/quantity recharge (Env 1) topping the group.

8.3.3 Aggregation of alternatives

The Weighted Summation Method (WSM) was applied for the aggregation of scores and weights with the aid of the following equations

$$P = \Sigma(w_j x_{ji}) \tag{8.2}$$

$$P = W_{env1} S_{env1} + \ldots + W_{eco5} S_{eco5} \tag{8.3}$$

The aggregation of alternatives using the combined weights of all experts is shown in Table 8.6.

Table 8.6: Aggregated values for sites and rank

Site	Aggregated value	Rank number
1	0.587	3
2	0.608	4
3	0.505	2
4	0.454	1

8.4 Sensitivity Analysis and Validation of Results

8.4.1 Sensitivity analysis

Although the use of experts brings about some elements of subjectivity, this is a problem normally encountered and is inherent when making choices. A way to overcome such diverse views was to carry out sensitivity analysis as discussed in section 3.4.5.

Four different scenario analyses were carried out to determine the robustness of the weights represented in Table 8.7. The first scenario was applying the actual weights obtained from the questionnaire survey. The second scenario was using equal weights, the third was the average values from all experts, while the forth and fifth scenarios were assigning 50% of the weights to Environment and Economic criteria respectively.

Table 8.7: Weights for the sub-criteria for the different scenarios

Main criteria	Scenario Sub-criteria	1 Actual	2 Equal	3 Experts Average	4 50% Env	5 50% Eco
Environmental	Env 1	0.071	0.060	0.071	0.083	0.042
	Env 2	0.070	0.060	0.069	0.083	0.042
	Env 3	0.068	0.060	0.068	0.083	0.042
	Env 4	0.058	0.060	0.057	0.083	0.042
	Env 5	0.055	0.060	0.055	0.083	0.042
	Env 6	0.068	0.060	0.068	0.083	0.042
Social	Soc 1	0.043	0.060	0.056	0.045	0.042
	Soc 2	0.052	0.060	0.067	0.045	0.042
	Soc 3	0.042	0.060	0.054	0.045	0.042
	Soc 4	0.032	0.060	0.041	0.045	0.042
	Soc 5	0.043	0.060	0.055	0.045	0.042
	Soc 6	0.038	0.060	0.048	0.045	0.042
Economic	Eco 1	0.068	0.060	0.055	0.045	0.100
	Eco 2	0.074	0.060	0.060	0.045	0.100
	Eco 3	0.071	0.060	0.057	0.045	0.100
	Eco 4	0.073	0.060	0.059	0.045	0.100
	Eco 5	0.074	0.060	0.060	0.045	0.100

The results of aggregated values for the different scenarios are displayed in Table 8.8.

Table 8.8: Sensitivity analysis for prioritization of contaminated sites

Site	Actual	Rank order	Equal	Rank order	Experts Avg	Rank order	50% Env	Rank order	50% Eco	Rank order
1	0.587	3	0.592	3	0.597	3	0.591	3	0.550	3
2	0.608	4	0.623	4	0.614	4	0.604	4	0.599	4
3	0.505	2	0.527	2	0.514	2	0.479	2	0.525	2
4	0.454	1	0.475	1	0.466	1	0.429	1	0.468	1

The five different scenarios used in testing the robustness of the weights selected gave the same ranking order for the four sites. Site 4 was ranked the highest with a value of 0.454 while Site 2 ranked last with a value of 0.608, implying that the former would require more remediation and/or rehabilitation that the later.

8.4.2 Validation of results

Unlike in the sensitivity analysis where results from WSM were solely used, the validation of the results was accomplished using the Analytical Hierarchy

Process (AHP). This was accomplished in two stages. The first stage involved the validation of weights, while the second stage consisted of the utilization of information obtained from potential users (in this case, regulators comprising of Department of Petroleum Resources staff) to validate the aggregated values for prioritization of contaminated sites.

8.4.2.1 Validation for weight assignment

The AHP discussed in section 3.4.3.2 was utilized for the validation of criterion weights and it involves the following steps.

Step 1 for the AHP procedure involved decomposing the problem as discussed in section 8.2 and shown in Figure 8.1. This was accompanied by step 2 where questionnaires (Appendix C.3) were used to elicit relative importance (ranging from 1 – 9) of selected criteria from experts. The questionnaires were then analysed to obtain a single value from each expert group. The modal value was selected as the group median which had been used earlier would have been meaningless due to the wide range of intensity of importance. The values obtained in step 2 were then inserted into a matrix for calculation of criteria weights.

In step 3, the pairwise comparisons are the input of the analysis that calculates the relative priority of each alternative. 'Relative' in this context means the priority with respect to a particular criterion (Huizingh and Vrolijk, 1995). In calculating the relative priorities, AHP uses the eigenvalues and eigenvectors of the pairwise comparison matrix (Saaty, 1980). However, in this work an approximation approach which is much easier to understand was used. The difference between the approximation method and the actual calculation of eigenvalues and vector has been placed in the error margin of 1%. The procedure is as follows

First, the pairwise comparisons are represented in a matrix shown in Table 8.9.

Table 8.9: Pairwise comparison matrix

	P1	P2	P3
P1 Environmental	1		
P2 Social	2	1	
P3 Economic	3	4	1

The upper diagonal of the matrix is not filled because each pair of alternatives is judged only once. The matrix is filled by deriving the remaining pairwise comparisons from the judgements the expert manager made. The diagonal is filled with 1's, because each alternative equals itself

The comparisons are then 'mirrored' on the diagonal, for example, if P1P2 equal 2 then P2P1 is given a value of half. The full pairwise comparison matrix is shown in Table 8.10.

Table 8.10: Full comparison matrix

	P1	P2	P3
P1 Environmental	1	½	1/3
P2 Social	2	1	1/4
P3 Economic	3	4	1

For each column the totals are calculated. Then the columns are normalised by dividing each value by its column total. The normalised pairwise comparison matrix is displayed in Table 8.11.

Table 8.11: Normalized comparison matrix

	P1	P2	P3
P1 Environmental	1	1/2	1/3
P2 Social	2	1	¼
P3 Economic	3	4	1
Total	**6.00**	**5.50**	**1.58**
Normalization	P1	P2	P3
P1	**0.17**	**0.09**	**0.21**
P2	**0.33**	**0.18**	**0.16**
P3	**0.50**	**0.73**	**0.63**
Total	1.00	1.00	1.00

The relative priority for each alternative is determined by calculating the mean of the values in a row, as presented in Table 8.12.

Table 8.12: Relative importance of criteria using AHP for DPR experts

Normalization	P1	P2	P3	Sum	Average (relative importance)
P1	0.17	0.09	0.21	**0.47**	**0.16**
P2	0.33	0.18	0.16	**0.67**	**0.22**
P3	0.50	0.73	0.63	**1.85**	**0.62**
Total	1.00	1.00	1.00		1.00

Because the analyst judges every possible pair of alternatives, a measure of consistency was calculated. If A is twice as preferable to B, and B is twice as preferable to C, then, in case of perfect consistency, the decision maker should prefer A four times to C (Huizingh and Vrolijk, 1995). Deviations in these judgements are represented by the consistency ratio (CR) and calculated using Equation 8.1.

$$CR = \frac{CI}{RI} \qquad (8.1)$$

where CI is the Consistency Index derived from (Equation 8.2)

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (8.2)$$

where λ_{max} is the largest eigen value of the comparison matrix and n is the number of criteria. *RI* is the Radom Consistency Index which can be obtained from existing table that established the relationship between n and RI.

λ_{max} was computed by summation of products between each calculated relative importance value and the sum of column for each full matrix. Therefore λ_{max} was calculated as

$$(6 \times 0.16) + (5.5 \times 0.22) + (1.58 \times 0.62) = 3.15 \qquad (8.3)$$

The normalized weights were calculated for each group of experts and the results are presented in Table 8.13

Table 8.13: Normalized weights for main criteria from experts using AHP

Criteria	DPR	Oil Company	FMEn	All Experts
Environmental	0.16	0.26	0.31	**0.16**
Social	0.22	0.26	0.20	**0.25**
Economic	0.62	0.47	0.48	**0.59**

Only the CR calculated for 'All experts' gave a value that was less than 0.10, therefore it was the most consistent among the group.

In comparison with the weights derived using WSM (Table 8.5), it can be observed the weights provided by experts from DPR and oil company were consistent for only the social criteria. Weights assigned to environmental and economic are at par, therefore more evaluation is required to arrive at comparable weights. This should involve more experts in a participatory group discussion.

8.4.2.2 Validation of aggregated values for alternatives

Two procedures were used in the validation of aggregated values. The first was carried out in accordance with the methodology described by Borenstein (1998). It involves the validation through questionnaires and interviews of potential users of the MCDS framework. This method was found to be an attractive option due to the complexity involved in the prioritization process. The main objective of this validation method is to achieve consistency between the final values obtained as presented in section 8.3.3 and values obtained by potential users. In this case the potential users of the developed framework for prioritization of contaminated sites are planners and policy makers. Experts from the Department of Petroleum Resources (DPR) were thus involved in the validation process using the weights displayed in Table 8.14.

Table 8.14: Weights used for validation of results for prioritization of contaminated sites

Sub-criteria	Code	DPR
Effect on groundwater quality/quantity recharge	Env 1	0.076
Soil contamination	Env 2	0.073
Impact on vegetation	Env 3	0.076
Characteristics of hydrocarbon spill	Env 4	0.055
Land cover land use change	Env 5	0.063
Degradation of surface water quality	Env 6	0.069
Dislocation of persons	Soc 1	0.055
Health impact	Soc 2	0.073
Aesthetic effect	Soc 3	0.055
Effect on cultural resources	Soc 4	0.037
Psychological attitude resulting from spill	Soc 5	0.048
Communal conflict	Soc 6	0.037
Type of income affected	Eco 1	0.046
Magnitude of economic loss	Eco 2	0.061
Effect on sustainable income	Eco 3	0.051
Effect on property value	Eco 4	0.060
Intensity of economic activity around spill	Eco 5	0.064

The aggregated values for the four sites are shown in Table 8.15. Environmental criteria were generally assigned higher values, entailing that they are of more significant compared to social and economic criteria. Social sub-criteria, effect of cultural resources and communal conflict were given the lowest values of 0.37.

Table 8.15: Validated results for prioritization of contaminated sites and their ranking based on DPR expert opinion

Site	Aggregated value	Rank number
1	0.603	3
2	0.606	4
3	0.505	2
4	0.461	1

The results obtained from using weights elicited from potential users of the framework are in close agreement with those earlier obtained from other experts.

The second method involved the use of weights obtained using the AHP method presented in Table 8.13. The aggregated weights for the different expert groups are displayed in Table 8.16 and Figure 8.9.

Table 8.16: Rank order (aggregated values) from AHP derived weights

	DPR	Oil Company	FMnE	All experts
Site 1	2 (0.479)	3 (0.509)	3 (0.509)	2 (0.485)
Site 2	4 (0.532)	4 (0.549)	4 (0.544)	4 (0.538)
Site 3	2 (0.479)	2 (0.475)	2 (0.458)	2 (0.485)
Site 4	1 (0.427)	1 (0.425)	1 (0.408)	1 (0.433)

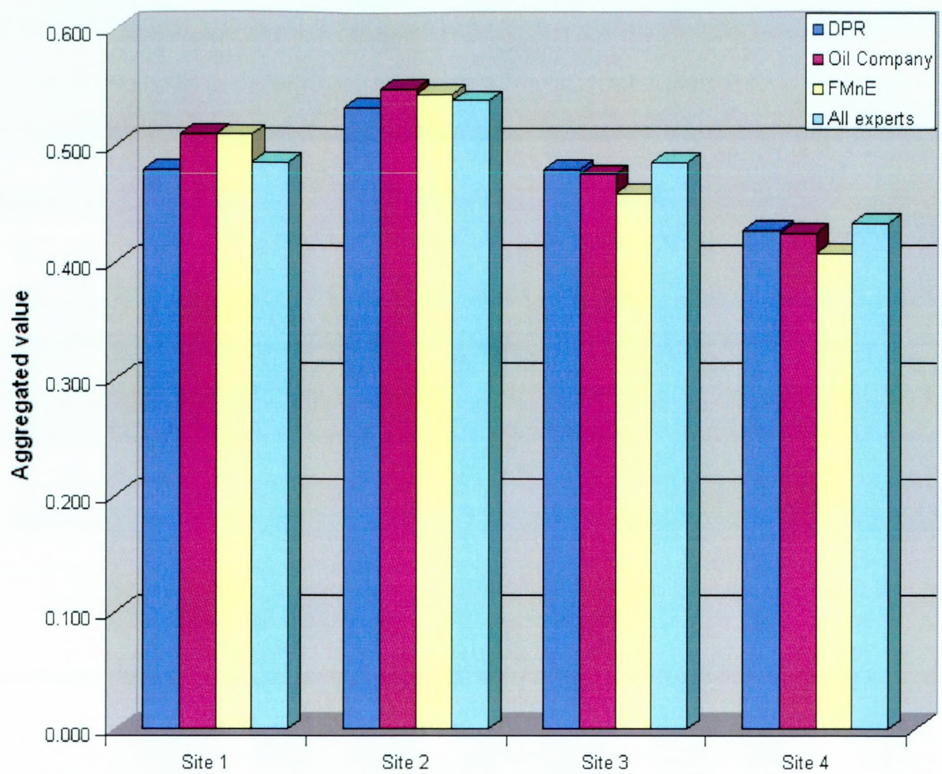

Figure 8.9: Aggregated values using AHP derived weights

Table 8.16 and Figure 8.9 show that Site 4 was ranked the lowest while Site 2 ranked the highest, validating the results presented in Table 8.6. Sites 1 and 3 tallied in rank for DPR and All experts. These results are comparable with those obtained using the weights derived from the WSM. This shows consistency of results in the two methods used. A summary of all the different weights applied for the estimation of the aggregated values is given in Table 8.17.

Table 8.17: Summary of aggregated values

		Results of sensitivity analysis				Validation of results				
						WSM	AHP			
	Actual	Equal weight	Expert average	50% Env	50% Eco	DPR	DPR	Oil Company	FMnE	All experts
Site 1	3 (0.587)	3 (0.592)	3 (0.597)	3 (0.591)	3 (0.550)	3 (0.603)	2(0.479)	3(0.509)	3(0.509)	2(0.485)
Site 2	4 (0.608)	4 (0.623)	4 (0.614)	4 (0.604)	4 (0.599)	4 (0.606)	4(0.532)	4(0.549)	4(0.544)	4(0.538)
Site 3	2 (0.505)	2 (0.527)	2 (0.514)	2 (0.479)	2 (0.525)	2 (0.505)	2(0.479)	2(0.475)	2(0.458)	2(0.485)
Site 4	1 (0.454)	1 (0.475)	1 (0.466)	1 (0.429)	1 (0.468)	1 (0.461)	1(0.427)	1(0.425)	1(0.408)	1(0.433)

Table 8.17 indicates a consistency in the order of ranking of all the sites. This implies that the weights obtained from the different experts did not vary significantly to affect the rank order.

8.5 Summary

The framework developed in this research has been applied for the prioritization of contaminated areas. It highlighted the ability of MCA to integrate both qualitative and quantitative data in the decision process. Also the involvement of stakeholders for the eliciting of weights and scores adds to the advantage of using the MCA method.

The use of indicators/criteria for sustainable development has been applied for the prioritization of contaminated sites and it gives the framework a multi-disciplinary approach to decision making.

Chapter 9 : Conclusion and Recommendations

9.1 Introduction

The goal of this research work was to develop a multi-criteria decision support (MCDS) framework for environmental impact and vulnerability assessment of oil activities. The MCDS framework has the ability to integrate sustainable issues from a multidisciplinary perspective, with the added advantage of incorporating the diverse views of experts and stakeholders for the prioritization of contaminated sites as a result of oil production and transportation activities.

Based on an in depth review on the extent to which the aim and objectives of this research work have been reached, this chapter presents the conclusions that can be drawn from it.

9.2 Conclusion

A summary on the findings of this research work are presented in the following sub-sections

9.2.1 The need for the framework

In this study, much attention has been given to the review of the physical and social environment. This was carried out to provide a better understanding of the dynamics of the region. The legislative and institutional policies guiding oil operations were also reviewed to establish existing lapses that has resulted in the degradation of the Niger Delta region.

An exhaustive literature review presented in Chapter 2 revealed the problem being undertaken in this research. This was better understood by providing and introduction on the peculiarity of the selected area of study. It was evident that there was an absence of a framework to aid decision makers in environmental impact and vulnerability assessments for monitoring post developmental activities, with particular reference to oil industries.

9.2.2 Identification and selections of participants

A vital aspect of the developed MCDS framework was the involvement of experts who essentially provided relative importance to selected criteria and stakeholders - host community members (for the derivation of criterion scores). The end users of such framework are planners or policy makers who require such tool for the better planning and management of the environment. Stakeholders for instance, host community members where projects and industries are sited are also beneficiaries of the developed framework as decision outcome could be perceived to be credible and transparent.

From the extensive investigation carried out by the researcher there was dearth in information required for quantitative environmental assessment. Therefore, it became necessary to obtain such information from experts specializing in the fields of environment and natural resources. Expert knowledge was essentially utilized in determining threshold values of criteria in terms of their relative importance. Experts were divided into two groups; the decision makers who are the end users of the framework and those from tertiary institutions specializing in the field of sustainable development.

9.2.3 Concepts and tools for the development of framework

Despite the fact that EIA is an intrinsically complex multi-dimensional process that is used in assessing the environmental implication of a decision to enact legislation, to implement policies and plans, or to initiate development projects, the second aspect of the literature review presented the concepts and tools required in the framework in order to provide fundamental knowledge about studies of EIA for past developmental activities. For this purpose, the most important descriptions of the definition of EIA, and the concepts and tools required have been outlined in Chapter 3. The major concept applied in the structuring of the framework was the DPSIR, while the major tools used included GIS, and MCA. The application of MCA in the framework improved the integration of stakeholder views and sustainability criteria. This to a large extent aided the transparency and the credibility of decisions reached. The immense attention focused on EDSS indicates that there is a move in the scientific community to extend research objectives from pure analysis towards application in decision making as this research work depicts. Stakeholder involvement which has been absent in previous DSS application has been addressed in this research work.

9.2.4 Data sources for framework

Data for framework has been obtained from different sources as presented in Chapter 4. The chapter also discussed the integration of different tools and techniques including stakeholder involvement into decision-making process.

It is necessary to utilize up-to-date spatial information for utilization in the MCDS framework and Chapter 5 provides a rapid and cost-effective method for obtaining such information from remotely sensed (satellite) data. A hybrid classification method was developed in this study to improve the accuracy assessment of the derived landcover maps. The method made use of the strengths of the supervised (maximum likelihood) and unsupervised (ISODATA) in combination with conditional statements to achieve this goal. The hybrid method showed an improved classification accuracy of 22% and 7% for the 1987 and 2002 land cover maps respectively. The derived land cover map of 2002 was used as the baseline data for environmental vulnerability assessment in Chapter 7.

Major land cover changes were detected with the highest depletion of 9% occurring in the natural forest land cover class, while the greatest increase of 10% was recorded in exposed/built-up areas. Land cover change information could not be applied in the framework due to the spatial and temporal resolution of satellite images used.

The need to establish the characteristics of spill sites with respect to level of contaminants present, led to the application of statistical analysis. Chapter 6 describes the techniques used to establish the nature and spatial distribution of physico-chemical variables in soil and water. Multivariate statistical analysis was applied to surface and groundwater samples. Principal component analysis (PCA) and factor analysis (FA) were used for reducing data redundancy and to establish relationships among measured variables. Cluster analysis (CA) was introduced to detect spatial similarity among variables. Results showed where hydrocarbon was prevalent and other elements that are closely associated with it. For surface water, Zn was seen to be associated with TPH, while Turbidity and Ni were in close association with TPH in groundwater samples. Such information is relevant for use in the framework where several sites are required to be prioritized for remediation/rehabilitation purposes.

9.2.5 Application of framework

This research has revealed a novel approach involving remotely sensed data, MCA and GIS technology for vulnerability assessment of targets as a result of the close proximity of targets to oil production and transportation facilities. Such spatial analysis as presented in Chapter 7 will improve policy/decision making or design of strategies/projects aimed at conflict management among communities.

The use of indicators/criteria for sustainable development discussed in Chapter 3 was applied for the prioritization of contaminated sites. This gives the framework a multi-disciplinary approach to decision making. The integration of different analytical tools and techniques such as GIS not only exposes the importance for the integration of different types of data, it also adds a spatial dimension to the vulnerability assessment. The incorporation of SMCA into the GIS made the analysis of spatial information feasible for vulnerability assessment.

The application of the framework for prioritizing contaminated areas is presented in Chapter 8. It highlighted the ability of MCA to integrate both qualitative and quantitative data in the decision process. Also the involvement of experts and stakeholders for eliciting weights and scores adds to the advantage of using the MCA method.

The framework has created a capability to combine various forms of information from different sources, therefore establishing a favourable condition for stakeholder involvement especially where there is a need for transparency and credibility in the applied techniques.

9.2.6 Overall conclusion

By developing the framework, the study has shown the potentials of integrating remote sensing data, GIS and field survey in the vulnerability and impact assessment of oil production and transportation activities. Based on the techniques described and results obtained using the Niger Delta a case study, it can be concluded that the developed framework is a suitable tool to assist decision makers in prioritizing contaminated areas as a result of oil activities. The framework also provides decision makers a structured multidisciplinary approach that incorporates both experts and stakeholders views in an explicit and transparent manner. This to a large extent helps to reduce conflict and creates understanding among vested interest groups. Although the framework focussed on oil related activities, there is the potential of its application in other vulnerability and post-impact assessment of mineral resources activities in the mining sector and to other areas experiencing similar problems.

The main limitation of the research which is normal for any study of this nature is time constraint. Due to the multidisciplinary nature of the framework developed, it was difficult to cover all areas especially the social and economic aspects with the same level of detail. The emphasis in this research has been mainly on the environmental aspects with the social and economic aspects covered with fewer amount of details.

9.3 Problems Encountered and Recommendation for Further Research

The main challenges encountered in the development and application of the MCDS framework, were associated with the integration of GIS and MCA and in the operational validation of the use of SDSS in real-world spatial problems

Application of framework was faced with following problems:

- Necessary data for vulnerability assessment and prioritization of contaminated areas were not available for every LGA

- All spatial data had to be converted to the same geo-referencing system. As the data were sourced from different organisations that used different local reference systems, there were some spatial mismatches, when they were all converted to the same geo-referencing system.

- Loss of data was encountered while integrating spatial data from different sources. This was as a result of data conversion from one format to the other, for instance from vector to raster. This was more prominent in the attribute data conversion.

- The sources of data used for vulnerability assessment and prioritization of contaminated sites were numerous and diverse. However, in some cases they are not useable. For instance landcover change, where the time span between the available images was quite large (from 1987 to 2002).

The satellite images (Landsat) used to extract land cover classes were acquired in 1987 and 2002; therefore more recent images are required to establish recent trends. Also the freeware images had a spatial resolution of 30m, thus limiting the amount of accurate information that can be obtained. Further assessment is required with images of higher spatial resolution such as IKONOS (1m – panchromatic and 4m – multispectral) and Quickbird (2.8m). Additionally, hyperspectral images such as ASTER with 14 spectral bands as compared to Landsat's 7 bands can also be utilized for the improvement of the land cover classes.

Due to the limitation of the image processing software used, the method used for land cover change detection was quite limiting as only the amount of change in percent could be deduced form this method. The change detection technique that involves a to-and-from change i.e. change of landcover from one type to another is recommended.

The use of field spectroscopy for obtaining in-situ data of different landcover classes for radiometric correction of images is needed to improve the accuracy landscape study.

The major obstacle which the researcher faced was the limited availability of socio-economic data for the validation of the framework. Majority of the stakeholders who participated in the scoring of criteria for the different Local Government Areas were resident outside their communities. A more exhaustive questionnaire survey which incorporates actual residents of host communities is recommended.

The weights derived using WSM and AHP methods, showed that there was consistency in the rank values for prioritizing contaminated sites in the study area. This implied that the rank values obtained for sites under investigation were not sensitive to the derived weights. Thus, further research on the utilization of other MCA techniques such as SWAT is required.

The researcher also proposes the development of an environmental management integrated software with a user-friendly interface where weights and scores of users of the framework can be incorporated for the derivation of vulnerable areas and the prioritization of contaminated areas.

Finally, it is recommended that the utilization of the framework for vulnerability and impact assessment of other mineral resources activities especially in the mining sector should be explored further.

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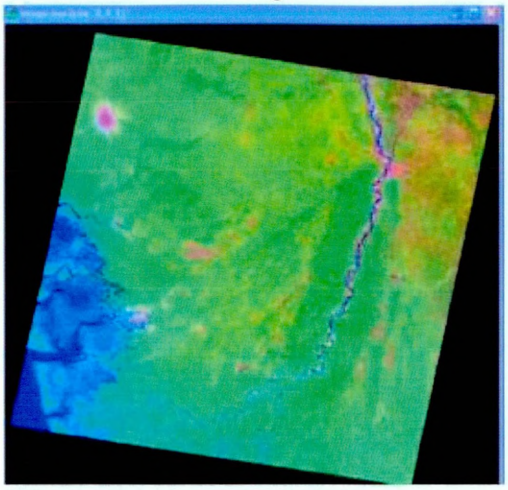
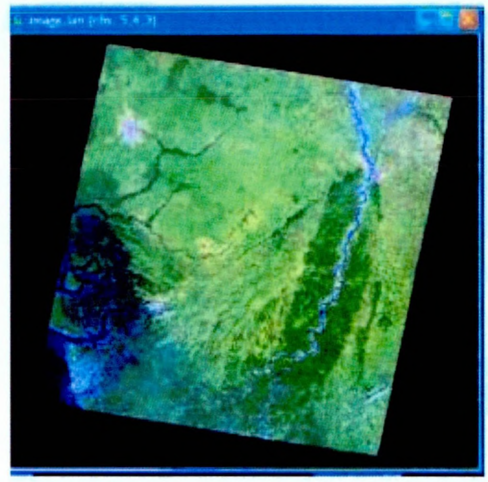
Appendices

Appendix A: Spatial and non-spatial data utilized in Multi-criteria Decision Support (MCDS) framework

A.1 Satellite raw images

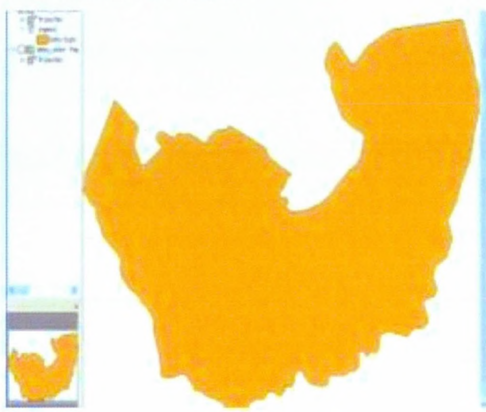


(a)Landsat 1986 image (bands 7-5-3).
Source: Global Land Cover Facility (2005)

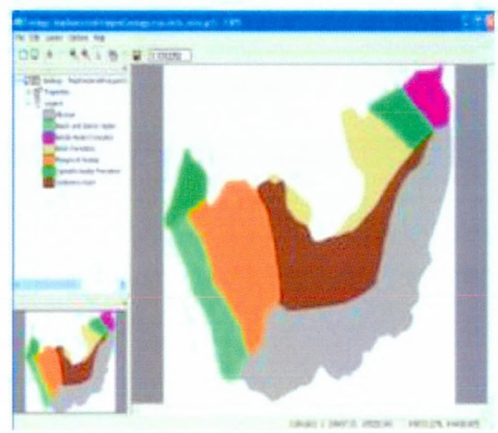


(b) Landsat 2002 image (bands 7-4-1)
Source: Global Land Cover Facility (2005)

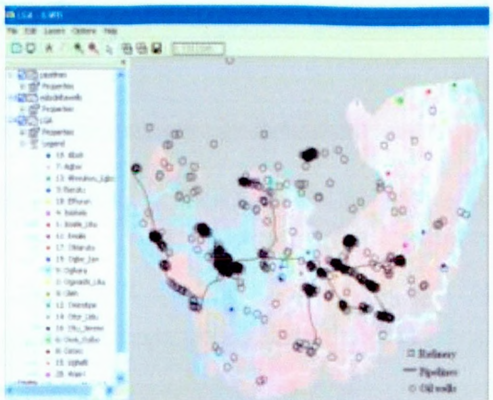
A.2 Thematic data



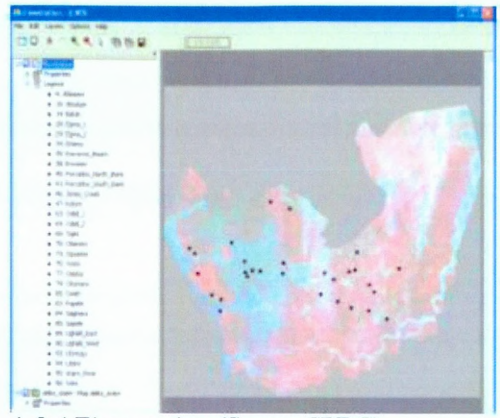
A.2.1 Delta State boundary extracted from Nigeriasat-1 image (Polygon map)



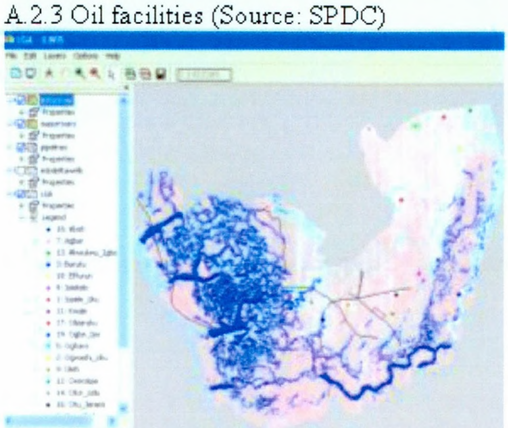
A.2.2 Geological map (Source: Geological Survey)



A.2.3 Oil facilities (Source: SPDC)



A.2.4 Flow station (Source SPDC)



A.2.5 Rivers (Source: SPDC)

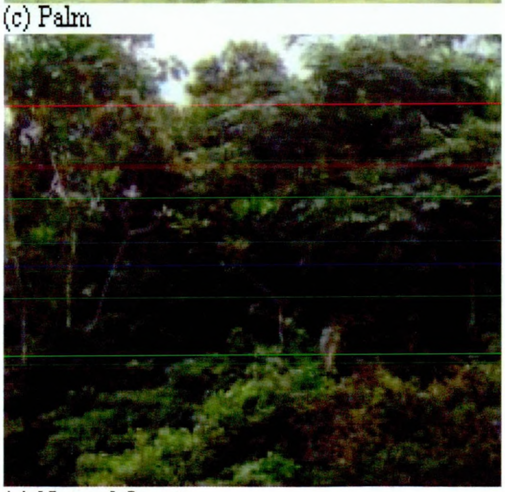
A3: Landcover classes


(a) Built-up/exposed areas


(b) Cultivated land

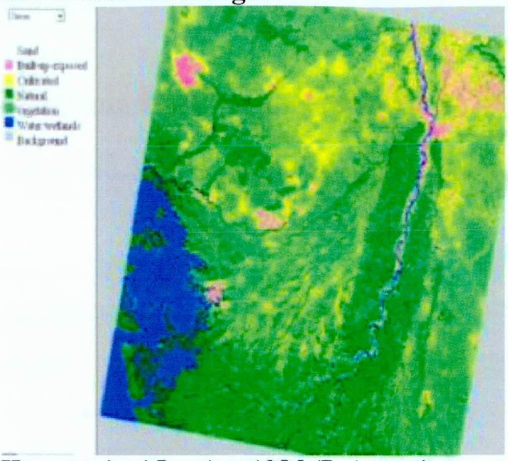

(c) Palm


(d) Mangrove and water

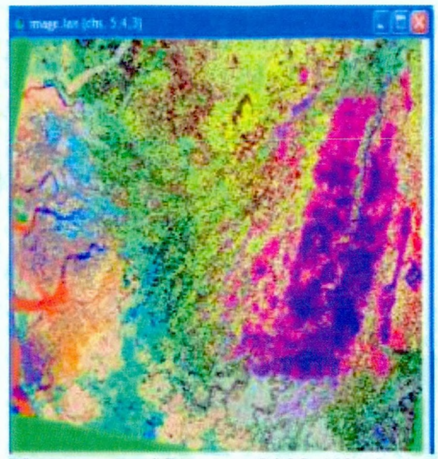

(e) Natural forest


(f) Thatched hut (typically found in the rural areas of the Niger Delta)

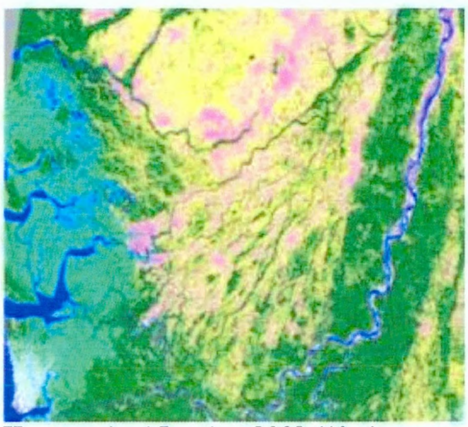
A.4 Classified images



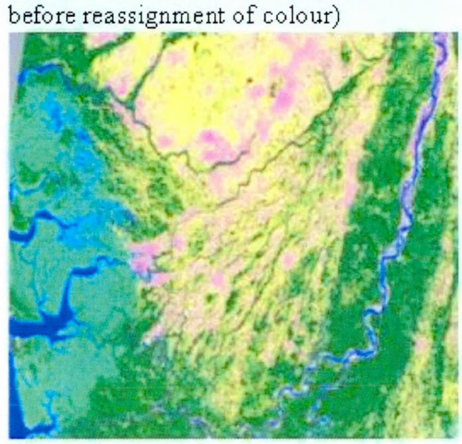
Unsupervised Landsat 1986 (7 clusters)



Unsupervised Landsat 2002 (40 clusters before reassignment of colour)



Unsupervised Landsat 2002 (40 clusters after reassignment of colour, with clouds)



Unsupervised Landsat 2002 (40 clusters after removal of clouds)

A.5 Letter of Request to Department of Petroleum Resources (DPR)

School of Contemporary Science
University of Abertay
Dundee
Scotland

18 April, 2005

The Operations Controller
Department of Petroleum Resources (DPR)
Warri, Delta State
Nigeria

Dear Sir,

REQUEST FOR RESEARCH MATERIALS ON THE NIGER DELTA
I am a Petroleum Technology Development Fund (PTDF) scholar, currently carrying out my PhD research work in the Niger Delta region of Nigeria. My area of interest is on the application of remote sensing and GIS techniques in investigating environmental degradation, using a site in the Niger Delta as my case study.

Kindly assist me in obtaining the following:

1. A map showing the oil pipelines of the various oil companies in the Niger Delta. It should cover pipelines from their rig sites to the refineries, and then from the refineries to other outlets in Rivers and Delta States.
2. Digital maps (scale 1:50,000) produced by the Niger Delta Environmental Survey (NDES), depicting land use and vegetation pattern in the Niger Delta.
3. The Niger Delta Environmental Survey (NDES) phase two report.
4. The Department of Petroleum Resources (DPR) Environmental Guidelines and Standards for the Petroleum Industry.

I will be grateful if my request is approved and given an early response.

Thank you.

Yours faithfully,

Omo-Irabor O.O. (Mrs)
PhD research student

Appendix B: Soil and water sampling and analysis

B.1 Standards and methods for soil and water analysis

Test parameter		Standard test method	Description of method
Variable	**Symbol**		
Physical parameter			
pH	pH	ASTM D1293B	pH meter
Temperature	TEMP		Thermometer
Total dissolved solids	TDS	APHA 208D/ASTM D1868	TDS meter
Conductivity	COND	APHA 145/ASTM D1125	Conductivity meter
Dissolved oxygen	DO	APHA 4500C/APHA 422B	Iodometric (Winkler reagent)
Turbidity	TURB	ASTM A214A	Turbidity meter
Total dissolved solids	TSS	ASTM D1868	Filtration technique
Total hardness	TH	APHA 122B	Titrimetric
Organic pollutant			
Biological oxygen demand	BOD_5	ASTM A507	Iodometric (Winkler reagent)
Chemical oxygen demand	COD	APHA 508/ASTM D1252	Open reflux
Oil and grease	OG	APR-RP 206/ASTM D3921	Solvent extraction
Major anion			
Chloride	Cl^-	APHA 2520B/ARI-RP 45	Titrimetric
Nitrate	NO_3^-	APHA 419C/ASTM D3867	Diazotization
Phosphate	PO_4^{3-}	APHA 425C/ASTM D515	Colorimetric
Sulphate	SO_4^{2-}	APHA 427C/ASTM B1233	Colorimetric
Major cation			
Calcium	Ca	ASTM D511	FAAS
Magnesium	Mg	ASTM D511	FAAS
Potassium	K	ASTM D93-77	FAAS
Sodium	Na	ASTM D93-77	FAAS
Heavy metal			
Lead	Pb	ASTM D3559	FAAS
Cadmium	Cd	ASTM D2576D	FAAS
Chromium	Cr	ASTM D168	FAAS
Zinc	Zn	ASTM D1691	FAAS

Test parameter		Standard test method	Description of method
Manganese	Mn	ASTM 301A	FAAS
Iron	Fe	ASTM D106C	FAAS
Nickel	Ni	ASTM D1886	FAAS
Hydrocarbon pollutant			
Total petroleum hydrocarbon	TPH	ASTM D3921	GCFID
Aliphatics	ALIP	ASTM D3921	GCFID
Aromatics	AROM	ASTM D3921	GCFID

B.2 Field survey

Field insitu test kit (for temperature, pH, and conductivity)

Winkler test kit (for DO)

Typical well (for groundwater sampling)

Soil sampling

B.3 Laboratory procedures and instruments


Soil sample preparation


Sample analysis


Flame Atomic Absorption Spectroscopy (FAAS)


Gas chromatograph flame ionized detector (GCFID)

Appendix C: Questionnaire survey

C.1 Questionnaire survey for the derivation of relative importance (weights) using weighted summation method (WSM) for vulnerability assessment

Discipline/Area of Specialisation……………………………………………………

Scale for comparison

Intensity of importance	Definition	Intensity of importance	Definition
1	Least important	4	Very strongly important
2	Moderately important	5	Extremely important
3	Strongly important		

Using the scale above give scores to the following criteria /sub-criteria according to their level of importance

Section A

Parameters for deriving Adaptive Capacity Index for conflict resolution

Criteria	Relative importance				
	1	2	3	4	5
Wealth creation and Employment					
Improved maternal health					
Universal primary education					
Poverty and hunger reduction					
Youth/gender issue					
Global partnership for development					
Reduction in infant mortality					
Combating common diseases					
Shelter and food security					
Power and energy					
Mass transportation					
Ensure environmental sustainability					

Section B

Potential Impact Assessment from oil activities

Criteria	Relative importance				
	1	2	3	4	5
Risk posed by oil facilities					
Exposure of Ecosystem and rural populace					
Sensitivity of the landscape to pollution					

Sub-criteria	Relative importance				
	1	2	3	4	5
Type of oil facility					
Age of oil facility					
Type of spill					
Estimated volume of spill					
Estimated area coverage of spill					
Distance of oil facility to rural settlements					
Distance of oil facility to agricultural land					

Sub-criteria	Relative importance				
	1	2	3	4	5
Dist of oil facility to surface water bodies					
Distance of oil facility to forest					
Size of population affected					
Topography					
Hydraulic soil property					
Depth to water table					
Geology					

Section C

Groundwater Vulnerability Assessment

Criteria	Relative importance				
	1	2	3	4	5
Depth of Water					
Net Recharge					
Aquifer media					
Soil media					
Topography (slope)					
Impact of the vadoze zone					
Hydraulic Conductivity of the aquifer					

Section D

Mangrove Vulnerability Assessment

Criteria	Relative importance				
	1	2	3	4	5
Population pressure					
Deforestation					
Civil conflicts					
Poverty					
Carbon dioxide					
Relative humidity					
Temperature					
Sea-level rise					
Precipitation					
Alien invasive species					
Pollutant input					

Section E

Prioritization of hydrocarbon spill sites

Criteria	Relative importance				
	1	2	3	4	5
Environmental					
Social					
Economic					
Sub-criteria	**Relative importance**				
	1	2	3	4	5
Effect on groundwater quality/recharge					
Soil contamination					
Impact on vegetation					
Characteristics of hydrocarbon spill					

Criteria	Relative importance				
	1	2	3	4	5
Environmental					
Social					
Economic					
Sub-criteria	**Relative importance**				
	1	2	3	4	5
Land cover/land use change					
Degradation of surface water quality					
Dislocation of persons from places of abode					
Health impact					
Aesthetic effect					
Effect on cultural resources					
Psychological attitude resulting from spill					
Communal conflict					
Type of income affected					
Magnitude of economic loss					
Effect on sustainable income					
Effect on property value					
Intensity of economic activity around spill site					

Thank you for taking the time to complete this questionnaire survey.
Your contribution is deeply appreciated.

C.2 Questionnaire survey for the derivation of scores using weighted summation method (WSM) for human vulnerability assessment

For each of the criteria, please indicate a score on a scale of (1-3). Where 1 = worst, 2=moderate and 3 = best as it applies to your community/Local Government Area (LGA).

Criteria	**Score**		
	1	**2**	**3**
Wealth creation and employment			
Improve maternal health			
Universal primary education			
Poverty and hunger reduction			
Youth/gender issue			
Global partnership for development			
Reduction in infant mortality			
Combating common diseases			
Shelter and food security			
Power and energy			
Mass transportation			
Ensure environmental sustainability			

Section A
Personal information for students

What is your gender?	(a) Male	
	(b) Female	
Level of study	(a) 100	
	(b) 200	
	(c) 300	
	(d) 400	
Name of Local Government Area		
Name of your community		

Section B
Personal information for host community members

What is your gender?	(a) Male	
	(b) Female	
How old are you?	(a) less than 21 years old	
	(b) 21 – 45 years old	
	(c) 46 – 64 years old	
	(d) Above 65 years old	
Name of Local Government Area/community		
How long have you stayed in this community?		
Type of occupation	(a) Farming	
	(b) Fishing	
	(c) Others - please state:	
What type of occupation has been most affected by oil activities?		
What is your level of educational attainment?	(a) Primary	
	(b) Secondary	
	(c) University	
	(d) Other	

Thank you for taking the time to complete this questionnaire survey.
Your contribution is deeply appreciated.

C.3 Questionnaire survey for the derivation of relative importance (weights) using analytical hierarchy process (AHP)

Name of organisation..

Scale for comparison

Intensity of importance	**Definition**
1	Equal importance
2	Equal to moderate importance of one factor over another
3	Moderate importance
4	Moderate to strong importance
5	Strong or essential importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extremely strong importance
9	Extreme importance

Using the scale given above, make a pair-wise comparison of the following criteria according to their level of importance (leave the grey cells blank)

		P1	P2	P3
P1	Environmental	1		
P2	Social		1	
P3	Economic			1

Thank you for taking the time to complete this questionnaire survey.
Your contribution is deeply appreciated.

C.4 Questionnaire survey for the derivation of scores for socio-economic criteria using weighted summation method (WSM) for prioritization of contaminated sites

For each of the criteria, please indicate a score on a scale of (1-3). Where 1 = least impacted, 2=moderate and 3 = most impacted as it applies to your community.

Criteria	Score		
	1	2	3
Dislocation of persons			
Health impact			
Aesthetic effect			
Effect on cultural resources			
Psychological attitude resulting from spill			
Communal conflict			
Type of income affected			
Magnitude of economic loss			
Effect on sustainable income			
Effect on property value			
Intensity of economic activity around spill			

Personal information for host community members

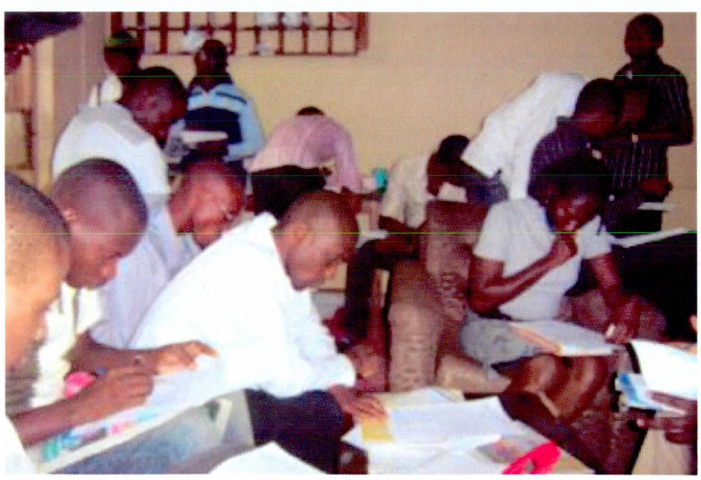
What is your gender?	(a) Male	
	(b) Female	
How old are you?	(a) less than 21 years old	
	(b) 21 – 45 years old	
	(c) 46 – 64 years old	
	(d) Above 65 years old	
Name of Local Government Area/community		
How long have you stayed in this community?		
Type of occupation	(a) Farming	
	(b) Fishing	
	(c) Others - please state:	
What is your level of educational attainment?	(a) Primary	
	(b) Secondary	
	(c) University	
	(d) Other	

Thank you for taking the time to complete this questionnaire survey.
Your contribution is deeply appreciated.

C.5 Stakeholders involved in questionnaire survey

Experts (Lecturers)

Host community members Isoko South LGA (Oleh)



Students from host community in Delta State

Appendix D: Advisors

Academia based Advisors

Prof Julius A. Okogie
Executive Secretary
National Universities Commission (NUC)
Abuja, Nigeria

Prof A.G. Onokheraye
Department of Geography
University of Benin
Benin-City, Nigeria

Prof Christopher O. Orubu
Professor of Economics
Department of Economics
Delta State University
Abraka, Nigeria

Prof Harry Staines (Retired)
Professor of Statistics
SIMBIOS
University of Abertay
Dundee, UK

Prof Phillipe Baveye
SIMBIOS
University of Abertay
Dundee, UK

Prof Tahirou Diaw
Department of Geography
Cheikh Anta Diop University
BP 16 599 Dakar-Fann,
Senegal

Drs Michiel Damen
Division of Applied Geomorphological Survey
ITC
Enschede, The Netherlands

Prof Martin G. Ogbe
Deputy Vice-Chancellor (Academics)
Delta State University
Abraka, Nigeria

Prof Bernard Ejechi
Rector
Delta State Polytechnic
Ozoro, Nigeria

Prof Cathy Di Domenico
Professor of Sociology
Division of Sociology
University of Abertay
Dundee, UK

Prof Solomon Isiorho
Chair & Professor of Geosciences
Department of Geosciences
Indiana University - Purdue University Ft. Wayne (IPFW) Fort Wayne, USA

Prof Duke Ophori
Department of Earth and Environmental Studies
Montclair State University, USA

Dr Samuel Olobaniyi
Associate Professor and Head
Department of Geology
Delta State University
Abraka, Nigeria

Dr Jimmy Adegoke
Associate Professor
Department of Geosciences
University of Missouri-Kansas City
Kansas City, USA

Academia based Advisors

Dr Jide Kufoniyi
Executive Director
Regional Centre for Training in Aerospace Surveys (RECTAS).
Ile-Ife, Nigeria

Dr Tsehaie Woldai
Geological Survey Division
ITC,
Enschede, The Netherlands

Dr Esohe G. Oboho
Department of Forestry and Wildlife
University of Benin.
Benin-City, Nigeria

Dr Isi A. Ikhuoria
Dept of Geography and Regional Planning
University of Benin
Benin City, Nigeria

Dr Ademola Omojola
Department of Geography
University of Lagos
Lagos, Nigeria

Industry based Advisors

Dr Jonathan O. Amakiri
Executive Secretary
Niger Delta Environmental Survey (NDES)/Shell Petroleum Development Company of Nigeria (SPDC)
Port-Harcourt, Nigeria

Dr A. Yammama
Health, Safety and Environment Department
Shell Petroleum Development Company of Nigeria (SPDC)
Warri, Nigeria

Dr Ganiyu I. Agbaje
National Space Research and Development Agency (NASRDA),
Abuja, Nigeria

Dr Sabastine Ekechukwu
Geomatics Department
Shell Petroleum Development Company of Nigeria (SPDC),
Warri, Nigeria

Ir Anne Mollema
Rotterdam Public Works
Department Engineer Consultants
Rotterdam
The Netherlands

Appendix E: Publications

MANGROVE VULNERABILITY ASSESSMENT USING SATELLITE IMAGES, SPATIAL MULTI-CRITERIA ANALYSIS (SMCA) AND GIS TECHNIQUES

O. O. Omo-Irabor[a,b,c,*], S. B. Olobaniyi[a,b], K. Oduyemi[a,c], J. Akunna[a,d], V. Venus[a,e], J. M Maina[a,f], C. Paradzayi[a,g,h]

[a] West African Management Coastal Initiative (WACMI)
[b] Department of Geology, Delta State University, P.M.B. 1, Abraka, Nigeria - omoomoirabor@yahoo.co.uk, sbolobaniyi@yahoo.com
[c] Division of Built and Natural Environment, School of Contemporary Sciences, University of Abertay, Bell Street. DD1 1HG, Scotland, UK – (o.omo-irabor, k.oduyemi)@abertay.ac.uk
[d] Urban Water and Technology Centre, University of Abertay, Bell Street. DD1 1HG, Scotland, UK - j.akunna@abertay.ac.uk
[e] International Institute for Geoinformation Science and Earth Observation, ITC, Enschede, Hengelosestraat 99, P.O. Box 6, 7500 AA, Enschede, The Netherlands - venus@itc.nl
[f] P. O. Box 99470, Mombasa, Kenya – mainajm@gmail.com
[g] Department of Geography, Environmental Management and Energy Studies, University of Johannesburg, Auckland Park Kingsway Campus, Johannesburg, South Africa
[h] Department of Surveying and Geomatics, Midlands State University, Gweru, Zimbabwe - cparadzayi@gmail.com

KEY WORDS: Satellite remote sensing, Data management, Spatial modeling, Environmental monitoring, Coastal management, Vulnerability

ABSTRACT:

Mangroves are known for their global environmental and socio-economic value. Despite their importance, mangrove like other ecosystems is now being threatened by natural and human-induced processes that damage them at alarming rates thereby diminishing the limited number of existing mangrove vegetation.

This project proposes an integrated spatial management framework for mangrove vulnerability assessment that utilizes information technology in conjunction with expert knowledge and multi-criteria analysis to aid planners and policy/decision makers in the protection this very fragile ecosystem.

1. INTRODUCTION

The lowland forests especially the mangroves have come under serious exploitation and constant threat of disintegration in recent times. There are roughly 17 million ha of mangroves worldwide that are gradually being depleted on a global scale (Gilman et al., 2006). Mangroves are known for their global environmental and socio-economic value, currently occupying 14,653,000 hectares of coastal area worldwide (FAO, 2003) and providing several important functions for numerous species that are dependent on such ecosystems for their existence. With an economic value of the order of US$200,000-900,000 per ha (Wells et al., 2006), coastal inhabitants benefit directly and indirectly from the many services rendered by mangroves such as provision of food, timber, fuel and medicine (Giri et al., 2007). Despite their importance mangrove vegetation like other marine ecosystems are now being threatened by a wide variety of natural threats(climate change, droughts, floods, land subsidence geologic erosion and sea level rise) and more recently human-induced (pollution, deforestation, invasion of exotic species, coastal development, saline water intrusion, sedimentation, sand mining, oil exploration and exploitation) processes. These processes damage the mangroves at alarming rates thereby diminishing the limited number of existing habitats. The cumulative effects of natural and anthropogenic pressures make mangrove wetlands one of the most threatened natural communities worldwide (Gilman et al., 2006).

When dealing with mangroves, researchers have developed the science and technology to quantify environmental degradation (Diop, 2003). However, there is deficiency in providing science-based solutions to decision makers, planners and managers who are more concerned with social and economic implications. Accurate predictions of changes to mangrove area and health, including those originating from climate change effects, enable advanced planning to minimize and offset anticipated losses and reduce threats to coastal development and human safety for specific sections of coastline (Gilman et al., 2006). Therefore, it becomes necessary to identify and estimate the relative importance of a number of socio-economic and environmental criteria to aid mangrove vulnerability assessment studies.

2. MANGROVE HABITAT AND VENERABILITY ASSESSMENT

Mangroves are found in about half of the 177 countries of the world (Wells et al., 2006), confined to 30° north and south of the equator (James et al., 2007) as shown in Figure 1. Mangroves strive in wetlands which are areas of ground that remain saturated at the surface for much of the year (Gilvear and McInnes, 1994). According to FAO (2003), climatic factors such as temperature and moisture contribute to their global distribution such that they are mainly located in the interface between land and sea in the tropical and subtropical regions.

Estimates of current mangrove extent vary significantly from one source to another, possibly because of the difference in definition, methodology, and land cover information used (Burke et al., 2001). Mangrove is used to refer to either the vegetation that belongs to intertidal community or to the community itself. The major types of mangrove include - *Avicennia / Sonneratia, Bruguiera caryophylloides, Rhizophora* and *Bruguiera gymnorhiza* (Ibrahim and Hashim, 1990).

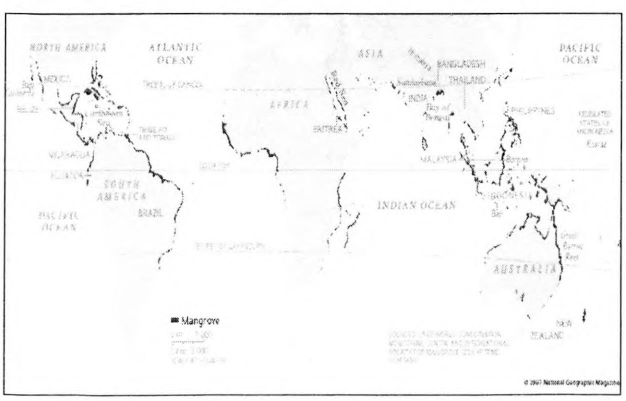


Figure1. Global distribution of mangroves (Source: National Geographic Magazine, 2007)

Vulnerability assessment of Vanuatu coastal areas has been conducted by (Phillips, 2000), (Gilman et al., 2006) particularly concentrated on mangrove vulnerability assessment to climatic change and sea level rise in the Pacific Islands. Vulnerability levels and trends need to be assessed regularly to provide early warning and response measures to reduce the economic costs (Diop, 2003). Vulnerability is the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt (Adger, 2006).

3. METHODOLOGY

A generalized flowcharts of the steps involved in mangrove vulnerability assessment is presented in Figure 2

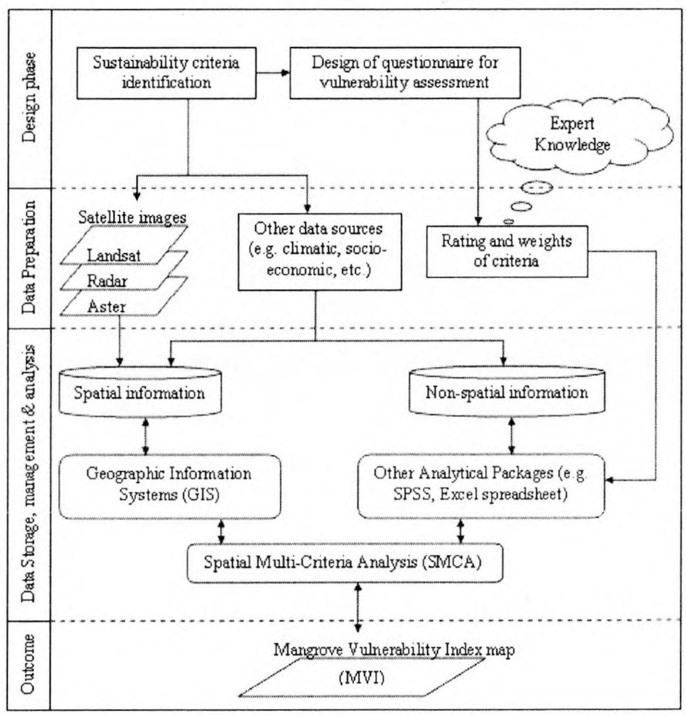


Figure 2. Flowchart for the determination of mangrove vulnerability

3.1 Use of Satellite Images

The development of modern earth observation techniques, such as the United States of America's - Landsat, IKONOS, Quickbird sensors, France's - SPOT, Nigeria's - NigeriaSat and India's IRS, with particular reference to multi-spectral/temporal remote sensing data greatly enhances the mapping and monitoring possibilities of the earth's features. Satellite images provide the spatial information for mangrove vulnerability assessment as accurate mapping by ground survey is extremely difficult, time consuming and expensive as a result of remote and inaccessible nature of the terrain. Digital image processing and GIS technologies therefore provide a rapid and cost-effective means of acquiring, storing and analyzing the necessary information.

Mangrove mapping using optical satellite images has been attempted by James et al. (2007) in the Niger delta region of Nigeria, Saleh (2007) in Abu Minqar Island located near the coastline of the Egyptian Red Sea, Giri et al.(2007) in Bangladesh and India and Benfield et al. (2005) in Punta Mala Bay, Panama. The major drawback of using optical images is their inability to discriminate between mangrove and other invasive plant species such as the Nypa palm. The images are also constrained by adverse atmospheric conditions such as clouds and haze.

Previous studies to discriminate between mangroves and the Nypa palm include the 1997 Niger Delta Environmental Survey, which used the post-classification re-coding rule. The post-classification methodology used two sets of rules: one that revised a supervised Thematic Mapper (TM) classification, using plant species density/height only and another that used density/height and ecology to modify the classification, to reduce the confusion between mangrove and Nypa. Although this procedure helped to improve the distinction between mangrove and Nypa, the several variations of the post-classification do not make it globally applicable in other mangrove region. This is further complicated by the spectral similarities between mangroves and Nypa palm making it extremely difficult to differentiate the two species (Niger Delta Environmental Survey, 1997).

This research proposes the utilization of Radar images using information of the backscatter characteristics of the different plant species in conjunction with optical sensors for improved mangrove identification and mapping. Additional satellite data obtained from either ASTER or SRTM for the creation of DEM will help to further improve mangrove post-classification accuracy.

3.2 Identification and Selection of Criteria for Mangrove Vulnerability Assessment

Expert knowledge is an essential aspect is the identification and selection of criteria for mangrove vulnerability assessment. Experts made up of lecturers in the fields of environment such as geology, microbiology and chemistry were involved in the identification of criteria for mangrove vulnerability and weighing of the criteria. The weights ranged from 1 - 5, where 1 = least important and 5 = most important. The criteria were based on those that address the sustainability of the mangrove ecosystem.

3.2.1 Socio-Economic Criteria

Population Pressure

The ability of mangrove ecosystems to adapt to environmental changes depends largely on their geographical location and the size and nature of the local human population. Also, Industrialization coupled with urban settlements impose a high demand for land. Therefore human population pressure is increasingly a contributory factor in the loss of the mangrove habitat globally. Information on population can be obtained from census figures.

Deforestation

High rates of deforestation in mangroves can be linked mainly to agricultural and aqua cultural activities. Hussin *et al* (1999) in (Paradzayi and Omo-Irabor, 2008) have shown that mangrove deforestation caused by establishment of shrimp ponds can be detected on all optical and radar images. There is increased correlation between the signal polarization and incidence angle with the ability of particular radar sensors to detect changes in mangrove environments. The crucial point is that the deforestation of mangrove is largely attributed to changing socio-economic conditions. Rates of deforestation can be extracted from temporal analysis of satellite images

Poverty

Poverty in the local populations often results from a destabilization of their social context and a resulting break in the provision of their traditional resources (Diop, 2003). This also leads to greater environmental pressures. Information on poverty can be obtained from http://www.ruralpovertyportal.org/english/regions/africa/nga/index.htm or by interview.

Civil Conflicts

Factors such as civil conflicts can have impact on mangroves' vulnerability (Diop, 2003). Information of civil conflicts can be sourced locally.

3.3.2 Environmental Criteria

Carbon Dioxide

The CO_2 content of the atmosphere is usually expressed in parts per million (ppm) by weight and the use of fossil fuels is expressed as so many tons of carbon burned per year. Estimation of the CO_2 in the atmosphere was estimated from the amount released from fossil fuel burning. The burning of fossil fuels presently releases 7 billion tons of carbon into the atmosphere each year in the form of carbon dioxide gas, CO_2.

Presently, the mangroves like other forest zones are sinks to the excess CO_2 emitted. They act as buffer protecting the environment from the full effect of global warming. Increased CO_2 enhances productivity but this is dependent on other limiting factors such as salinity, humidity, nutrients (Ball et al., 1997). Relevant data can be obtained form the United States NASA website http://data.giss.nasa.gov/co2_fung/

Relative Humidity

Water vapour is the most important heat-trapping greenhouse gas in our atmosphere. Specific humidity refers to the actual amount of water vapour in the air. Relative humidity relates to the saturation point, the amount of water vapour in the air divided by the maximum amount of water the air is capable of holding at a given temperature. As air temperatures rise, warm air can hold more water, and the saturation point of the air also increases.

Temperature

Mangrove species usually occur where annual temperature is high and temperature amplitude is small. Seasonal temperature changes of less than 10°C are favourable for good growth. The ideal temperature for photosynthesis is 35°C. Low temperature reduces the tree size, leaf area index and species composition of the flora as well as the complexity of communities. Typically, mangroves occur in areas where mean annual temperatures do not drop below 19°C (66°F) (Waisel, 1972). Short-term extreme temperatures of 4°C to 60°C can be tolerated but these should never suddenly arise, but rather increase or decrease slowly. According to Lovelock and Ellison (2007), increased air and sea temperatures generally lead to reduced productivity at low latitudes and increased winter productivity at high latitudes

Sea-Level Rise

Regional sea-level rise is affected by tectonic movements that can cause land subsidence or uplift. Natural and human induced sediment compaction can also exacerbate the impacts of sea-level rise. Humans contribute to land subsidence through coastal development that causes deficits in the sediment budget, shipping channels that cause bank erosion, groundwater or oil extraction that causes submergence, and dredging and mining that causes losses of land (McLeod and Salm, 2006). Global mean sea level is projected to rise 9 to 88 cm between 1990 and 2100 (Gilman et al., 2006). Estimation can be used to assess site-specific mangrove vulnerability to projected sea level rise.

Precipitation

Changes in precipitation patterns caused by climate change may have a profound effect on both the growth of mangroves and their areal extent (Field 1995; Snedaker 1995). Mangrove areas experiencing increased rainfall will experience an increase in area, with mangrove colonization of previously non-vegetated areas of the landward fringe, and there will an increase in diversity of mangrove zones and growth rates (Ellison, 2000).

Alien invasive species

A major anthropogenic factor contributing to the degradation and depletion of the mangroves is the invasion of the non-native Nypa palm (Nypa *fruticans*). The Nypa palm was first introduced in Calabar in 1906 and later in Oron in 1912. The species rapidly established itself successfully and in the process displaced the native mangrove vegetation (CEDA, 1997). Unfortunately, it failed to play the role of erosion control for which it was introduced to Nigeria; rather it has helped to reduce the firmness of the coastal sediments. Other problems caused by the presence of the invasive palm include the general habitat conversion with attendant reduction in fish catch, poor navigation, ecological degradation and loss of biodiversity.

Pollutant input

Important parameters are required for monitoring pollution level in coastal regions where mangrove strives. A wide variety of pollutants affects the world's mangrove. Pollutants include nutrients, pathogens, persistent organic pollutants and heavy metals, oil, and solid waste (Burke et al., 2001). Of particular interest are petroleum residues which can contaminate marine and coastal waters through various routes: accidental oil spills from tankers, pipelines, and exploration sites; regular shipping and exploration operations, such as exchange of ballast water; runoff from land; and municipal and industrial wastes (Burke et al., 2001). Also heavy metals also pose a threat to the survival of mangrove and those that are commonly monitored include cadmium, copper, mercury, lead, nickel, and zinc.

3.3 Application of GIS

In recent years GIS has become an invaluable information technology tool for a wide range of environmental applications, particularly for monitoring and studying the effects of humans in ecosystems that are difficult to access and analyse, such as mangrove habitats (Davis and Quinn, 2004). GIS combines diverse data and techniques into a convenient spatial analysis and mapping framework.

3.4 Spatial Multi-Criteria Analysis (SMCA)

Spatial decision problems usually involve a large set of feasible alternatives with multiple conflicting and incommensurate evaluation criteria (Malczewski, 2006). The problem is then to identify the best (i.e. the most preferred) alternative and also determine a ranking of the alternatives when all the decision criteria are considered simultaneously (Triantaphyllou et al., 1997). Spatial multi-criteria decision (SMCD) refers to the application of MCA in spatial context where alternatives, criteria and other elements of the decision problem have an explicit spatial dimension (Chakhar and Mousseau, 2007). Problems associated with SMCD typically involve a set of geographically-defined alternatives events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Jankowski, 1995, Malczewski, 1996).

Spatial planning and decision making requires methods that make the outcome more transparent and credible. The Integrated Land and Water Information System (ILWIS)-Spatial Multi-criteria Evaluation (SMCE), was selected for this study because it was designed for planning and decision making processes. SMCE window in ILWIS is an application that assists and guides a user in doing Multi-Criteria Evaluation (MCE) in a spatial way. This study aims at using ILWIS-SMCE which consists of three phases – problem analysis, design of alternatives and decision making form alternative options. SMCE also referred to as Spatial Multi-criteria Analysis (SMCA) method was used for determining relative importance of environmental conditions affecting the mangrove ecosystem, and applies Weighted Linear Combination (WLC) to develop a vulnerability map of mangrove systems.

3.4.1 Assignment of Criteria Ratings and Weights

Criteria ratings were mainly extracted from threshold values obtained from an exhaustive review of literature.

Weights were obtained from expert knowledge through a means of questionnaire survey. When reporting results from a non-parametric questionnaire survey, it is relevant to note that the mean and standard deviation which is usually associated with normal distributed sampling is not applicable. The median and range are used instead (Field, 2005). For the derivation of the central tendencies for weight the grouped median (GM) was calculated using the equation

$$GM = L + I * \left(\frac{N/2 - F}{f} \right) \qquad (1)$$

where:
L = lower limit of the interval containing the median,
I = width of the interval containing the median,
N = total number of respondents,
F = cumulative frequency corresponding to the lower limit,
f = number of cases in the interval containing the median.

This central tendency has the advantage over the median value as it allows one to recognize that, for example, a 5-point rating scale constrains responses to a small set of discrete values when the underlying attribute being measured is really a continuous scale.

3.4.2 Standardization and normalization of criteria

An important phase in vulnerability assessment is the standardization of input maps. The criteria for determination of mangrove vulnerability are usually measured on different scales; therefore standardization is necessary in order to obtain meaning estimate. Standardisation is applied to obtain comparable scales in raw data sets, to allow comparisons among criteria. It involves defining the ratings (values) of a parameter in [0, 1] using the appropriate function, to create a membership degree (gradient) of mangrove vulnerability (susceptibility) map.

In order for the weight values to be combined, the process of normalization was carried out by dividing each weight by the sum of the weights such that their total sum equals unity. The normalized weights were derived using the following equation (2)

$$z = y_i \Big/ \sum_{i=1}^{n} y_i \qquad (2)$$

Where z is the normalized weight value for the ith class, yi is the raw weight.

3.4.3 Evaluation using Weighted Linear Combination Method

In order to develop a method for the assessment of mangrove vulnerability, establishing the factors responsible for mangrove survival is an essential component. Creating a hierarchy is essential and it refers to the actual process of defining the overall goal, objectives, criteria and (if present) sub-criteria (Strager, 2002) Figure . Five different input parameters were used to model mangrove vulnerability in the study area. These parameters and their parametric effects on mangrove vulnerability were selected and rated by experts. Criteria selection were mainly based on effects of climatic change associated with mangrove survival (McLeod and Salm, 2006).

Geographic Information Systems (GIS) was used to evaluate multidisciplinary expert values associated with establishing mangrove vulnerability. Information collected (field survey) or obtained existing data (satellite images, vector maps, metrological etc) were used to develop sustainability criteria for vulnerability assessments to determine areas affected by natural and anthropogenic changes.

Evaluating mangrove vulnerability assessment essentially involves applying the Weighted Linear Combination (WLC) as displayed in Equation (3).

$$V = \sum_{i=1}^{n} w_i x_i \prod_{j=1}^{m} c_j \qquad (3)$$

where V is the vulnerability index, w_i is the weight of factors i, x_i is criterion score of factors i, n is the number of factors and c_j, is the criterion score (1 or 0) of constraints j and m is the number of constraints. In other words, Boolean images are created to represent each constraint, where the Boolean image has a value 1 for reclassified cells that satisfies the constraint and 0 otherwise.

3.5 Sensitivity Analysis

Sensitivity analysis examines the extent of variation in predicted performance when parameters are systematically varied over a range of interest, either individually or in combination (Proctor and Qureshi, 2005). Sensitivity analysis provides further confidence in a model, and indicates priority areas for refinement if further versions of a model are to be developed.

Although the use of expert knowledge brings about some element of subjectivity, this is a problem normally encountered and is inherent when making choices. A way to overcome such diverse views was to carry out sensitivity analysis. A sensitivity analysis of the results may be carried out in order to take into account the uncertainty in estimating some of the figures involved.

4. PRELIMINARY RESULTS

The grouped median of the derived weights with the corresponding standard error (SE) for the three expert groups are presented in Table 1 and Figure 3.

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A MULTI-CRITERIA DECISION ANALYSIS (MCDA) APPROACH TO CONFLICT MANAGEMENT USING STAKEHOLDER PARTICIPATION AND MILLENNIUM DEVELOPMENT GOALS (MDGS) AGENDA

Omoleomo Olutoyin Omo-Irabor[a,*], Kehinde Oduyemi[a], Joseph Akunna[b], Emmanuel Ekanem[a]

[a] Division of Built and Natural Environment, School of Contemporary Sciences, University of Abertay, Bell Street. DD1 1HG, Scotland, UK – (o.omo-irabor*, k.oduyemi, e.ekanem)@abertay.ac.uk
[b] Urban Water and Technology Centre, University of Abertay, Bell Street. DD1 1HG, Scotland, UK – (j.akunna@abertay.ac.uk)

ABSTRACT

The coastal regions of the world are endowed with enormous wealth with both natural and human resource. Strategically located along the continental margins, the region is inhabited by 60% of the world's population. This has led to competing interests often leading to social conflicts and environmental degradation. There is therefore the need to develop an appropriate multi-criteria decision analysis tool that can ensure the sustainable utilization of this unique environment.

An outline of a multi-criteria decision analysis (MCDA) framework to conflict management that incorporates multiple objectives is presented. Criteria based on Millennium Development Goals (MDGs) were identified for the determination of the social adaptive capacity of rural dwellers. Various stakeholders' interest (operators, developers, regulators, community members and other major experts) were directly incorporated into the approach to improve decision-making processes.

The paper applies the framework using the Niger Delta as a case study wherein MCDA is used as a tool for testing stakeholder responses to and improving expert assessment of conflict management. The framework has been found effective in enhancing stakeholder involvement in decision-making and useful in developing consensus-based approach to management of coastal protected area.

KEYWORDS: Multi-Criteria Decision Analysis (MCDA), Adaptive Capacity, Millennium Development Goals (MDGs), Stakeholder Participation, Niger Delta

1. INTRODUCTION

The causes of major crisis in some regions can oftentimes be traced to the natural resource control, environmental degradation, activities from outside the region and marginalisation of relevant stakeholders. (Zeng et al. 2001) noted that there are numerous interest groups in coastal zone, each of which has its own focus on particular aspects of coastal environment. The degradation of Niger Delta environment and the resulting crisis has led to socio-economic strangulation of the Nigerian economy. Thus there is need to address the current problem in order to inform policy makers with the appropriate approach to conflict resolution.

In order to secure sustainable development, an integrated approach that takes into consideration the Millennium Development Goals (MDGs) was applied. At the United Nations Millennium Summit held in September 2000, 147 Heads of State adopted eight MDGs, which set targets to reduce poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women by 2015 (United Nations Development Programme, 2005).

One approach to incorporating preferences of interest groups into formal decision analysis procedures is to use multi-criteria decision analysis (MCDA). Multi-criteria decision analysis has been widely applied to for mapping risks of agricultural pollution (Giupponi et al. 1999), to land use planning and management (Malczewski et al. 1997, ;Joerin and Musy 2000), environmental decision making (Kiker et al. 2005), flood vulnerability assessment (Yalcın and Akyurek 2004), potential degree of conflict associated with oil and gas production activities (Brody *et al.* 2006).

2. STUDY AREA

Delta State is located in Niger Delta region of Nigeria (Figure 1). About 80% of the population is engaged in Farming, Fishing and Hunting are the major occupations of the inhabitants of Delta State, with the remaining 20% engaged in other occupations. The State is the leading producer of Crude Oil from Onshore/Offshore and Natural Gas in Nigeria.

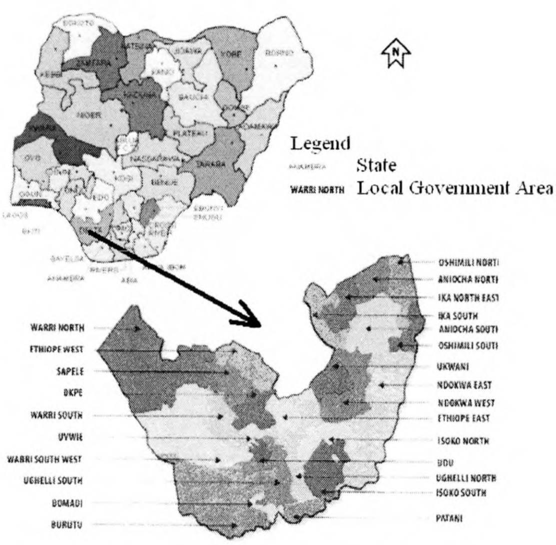

Figure 1: Map of Delta State and Local Government Areas

3. CONFLICT MANAGEMENT AND ADAPTIVE CAPACITY

Conflict management refers to the long term management of intractable conflicts. Conflict in the Niger Delta arose in the early 1990s due to tension between oil companies and host communities. Adaptive capacity is the ability of households to anticipate and respond to changes in coastal ecosystems and to minimize, cope with, and recover from the consequences. The concept of adaptive capacity was introduced in the IPCC TAR (IPCC 2001), according to which the factors that determine adaptive capacity to climate change include economic wealth, technology and infrastructure, information, knowledge and skills, institutions, equity and social capital (Metzger et al. 2006). In particular, adaptive capacity indicates a community's potential to cope with disturbances and take advantage of new opportunities, whether due to climate impacts (IPCC 2001) or conservation interventions.

4 MULTI-CRITERIA DECISION ANALYSIS

Almost all decision analysis methodologies share similar steps of organization in the construction of the decision matrix (Kiker *et al.* 2005). Decision processes have been defined as having three separate stages: problem identification, developing possible courses of action, and selecting a course of action from the choices available (Janssen 1996). Multi-criteria decision analysis (MCDA) tools can be applied to assess value judgments of individual decision makers or multiple stakeholders (Kiker *et al.* 2005). One of the advantages of an MCDA approach in group decisions is the capacity for calling attention to similarities or potential areas of conflict between stakeholders with different views, which results in a more complete understanding of the values held by others (Kiker *et al.* 2005).

The methodology utilized follows a three step approach. According to (Triantaphyllou et al. 1997), there are three main steps in utilizing any decision-making technique involving numerical analysis of alternatives:

- Problem definition for determining the relevant criteria and alternatives.
- Multi-Criteria Analysis (MCA) for attaching numerical measures to the relative importance (i.e. weights) of the criteria and to the impacts (i.e. the relative performance) of the alternatives on these criteria.
- Processing the numerical values to determine a ranking of each alternative.

4.1 Problem definition

This step involves

1. Definition of alternatives: identify the policy alternatives which are to be compared with each other;
2. Selection and definition of criteria: identify the effects or indicators relevant for the decision;
3. Identification and participation of Stakeholders: identify relevant stakeholder for the assignment of criteria scores and weights
4. Stakeholder questionnaire survey: solicit scores and weights among stakeholders
5. Estimation of scores and weights for each alternative: assign values for each effect or indicator for all alternatives

4.1.1 Definition of Alternatives

The hierarchical structure of consists of three levels Figure 2. Criteria or objectives can be divided into sub- or sub-sub-criteria (objectives) for additional information and for clarification and refinement (Qureshi and Harrison 2003). The first level represents the ultimate goal of the decision hierarchy (areas vulnerable to pollution), the second level represents the criteria and sub-criteria utilized in this work and the third level represents the options or alternatives. These alternatives should be described by some index (e.g. vulnerability index, risk index, adaptive capacity index etc.) and should be evaluated by means of some specific criteria, which constitute the decision rules (Critto et al. 2002)

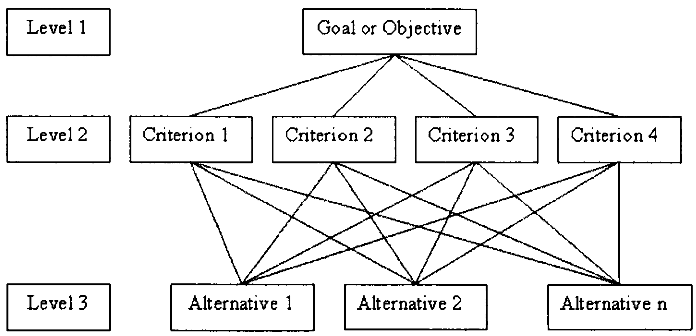

Figure 2: Problem with three different hierarchy levels (Qureshi and Harrison 2003)

4.1.2 Selection and definition of evaluation criteria for adaptive capacity index

The MDGs evaluation criteria for estimating the adaptive capacity index (Figure 3). It was selected because takes into consideration the socio-economic conditions that are vital to the existence of inhabitants of a place.

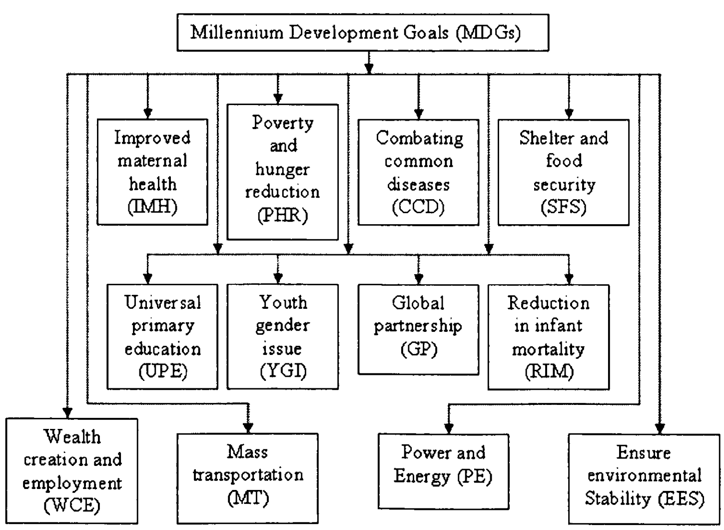

Figure 3: Millennium development goals for calculation of adaptive capacity

4.1.3 Identification and participation of stakeholders

No matter the context, stakeholder involvement is increasingly recognized as being an essential element of successful environmental decision making (Linkov et al, 2006). A stakeholder can be defined as a person or group who can affect or is affected by the outcomes of the decision at hand (Proctor and Qureshi 2005). Participation of stakeholders in this study was divided along these two main groups. The institutional/academic members (experts) provided expert opinion for assigning weights to the different criteria while the local residents (host community members) were solely for the purpose of obtaining information on adaptive capacity. This approach was adopted due to lack of socio-economic data. Sensitivity analysis was applied to test the robustness of the overall results.

4.1.4 Stakeholder questionnaire survey

Usually surveys are conducted using a questionnaire containing a number of queries and requesting stakeholders' response (Munier 2004). It is usually impossible and not economically feasible to physically to interview hundreds or thousands of people, unless a full, formal census is taken, therefore it is necessary to operate with samples, which allow one to work with a small, representative, number of people, and from them infer results about the whole population. Questionnaire survey has the advantage of minimizing facilitator and participant bias, as participants are expected to complete their questionnaires on individual basis. Since the survey was not exploratory in nature, and only elicited numerical responses, no information was lost through self-completion questionnaire survey

The questionnaire was prepared carefully taking into consideration input from different stakeholders. The initial questionnaire was sampled by these groups to ensure that the questions were well understood and the meaningful within the context of the research. Two different sets of questionnaire were disseminated; the first questionnaire was used to obtain scores from community members for analysis the quality of life through adaptive capacity while the second set of questionnaires in was used to elicit relative importance of selected criteria. The socio-economic survey provided a household-level adaptive capacity index in 23 out of the 25 Local Government Areas of Delta State (with the exception of Warri North and Oshimili South).

4.1.5 Estimation of scores and relative importance of criteria

SPSS Statistical package was been used to calculate the central tendency values e.g median, grouped median, and mean of scores and weights of the criteria. Since the scores were all obtained on a similar scale, further standardization was not necessary. The weights obtained for the 12 criteria were then normalized and combined as a weighted score for each criterion.

4.2 Multi-Criteria Analysis

Multi-criteria analysis involved a three-step approach; standardization of scores, normalization of weights and the ranking of alternatives.

4.1.1 Standardization of criteria

Standardization is essential when the unit of measure of the different criteria differ. Since all criteria were on a 1-3 scale, it was not necessary to carry out any further standardization procedure. A value of 1 indicates the worst outcome (ie the area has the highest negative impact) for each criterion, while 3 indicates the best outcome.

4.1.2 Normalization of weights

In order for the weight values to be combined, the process of normalization was carried by dividing each weight by the sum of the weights such that their total sum equals unity. A normalization of weights for Adaptive Capacity was accomplished using the formula

$$z = y_i \Big/ \sum_{i=1}^{n} y_i \qquad (1)$$

Where z is the normalized weight value for the ith class, y_i is the raw weight.

4.1.3 Ranking of alternatives

After the completion of standardization and normalization procedures for criteria, they were evaluated using the Weighted Summation method. It was chosen due to its simplicity and it also provides a complete ranking of alternatives (Balasubramaniam et al. 2007). Equation 3 was used in the calculation of Adaptive Capacity Index (ACI).

$$ACI = \sum(w_j x_{ji}) \qquad (2)$$

Weighted Summation is based on the concept of a weighted average and involves the simple process of multiplying a score against a criterion x_{ji} by the weight of that criterion w_j, before finding the sum of the weighted scores.

4.3 Sensitivity Analysis

Sensitivity analysis for was carried out to establish the influence of different weightings. The weightings of the criteria were varied according to the range of weightings identified by experts, from actual weighting for all objectives (scenario 1), to equal weighting (scenario 2) and finally where PHR was assigned 50% of the scores (scenario 3)

5. RESULTS

5.1 Criteria scores

Results of multi-criteria analysis for the derivation of scores for adaptive capacity criteria from stakeholders (host community members) are displayed in Table 1.

Table 1: Summary of score (grouped median) for Millennium development goals criteria from stakeholders (community members from local government areas in Delta State)

MDGs / LGAs	N	WCE	IMH	UPE	PHR	YGI	GP	RIM	CCD	SFS	PE	MT	EES
Aniocha North	7	1.71	1.83	2.00	1.83	1.83	1.29	2.43	1.71	1.80	1.33	1.43	1.57
Aniocha South	3	1.67	2.33	2.00	2.00	2.33	1.33	1.67	2.67	2.00	1.00	1.67	2.00
Burutu	3	1.00	1.50	1.33	1.33	2.00	1.67	2.00	1.67	1.33	1.00	1.67	2.00
Ethiope East	31	1.43	1.93	1.88	1.53	1.59	1.52	2.21	2.15	1.76	1.10	1.82	1.76
Ethiope West	4	1.50	1.50	2.00	1.67	1.75	1.75	2.25	2.00	2.00	2.25	2.25	1.75
Ika North-East	7	1.57	2.14	1.50	1.57	2.00	1.33	2.00	2.29	2.29	1.67	1.43	2.00
Ika South	4	1.50	1.75	2.00	1.67	2.00	1.50	2.25	2.33	2.00	1.00	1.50	2.00
Isoko North	5	1.80	2.00	2.20	1.80	1.20	2.00	2.60	2.40	2.25	1.50	2.00	1.60
Isoko South	2	2.00	1.00	1.00	2.00	2.00	2.00	1.50	1.00	1.50	1.50	1.50	1.50
Ndokwa East	1	2.00	2.00	1.00	2.00	1.00	1.00	2.00	2.00	1.00	1.00	2.00	2.00
Ndokwa West	3	1.33	1.67	2.00	2.00	1.67	1.67	2.67	2.33	2.00	1.33	1.67	2.00
Okpe	5	2.00	1.40	1.60	1.50	1.60	1.50	1.75	1.80	2.00	1.40	2.00	2.00
Oshimili North	4	1.75	1.50	2.00	1.25	1.50	1.50	1.75	1.75	2.00	1.00	2.25	2.00
Udu	4	1.67	2.00	1.67	1.50	2.00	1.67	2.00	2.00	1.50	1.50	1.25	1.25
Ughelli North	4	1.50	2.00	2.50	1.75	1.75	2.00	2.25	2.00	2.25	1.50	1.75	1.75
Ughelli South	6	2.00	2.00	2.17	1.40	1.83	1.40	2.00	1.67	1.83	1.50	1.83	1.50
Ukwani	2	1.00	2.00	1.00	1.00	1.50	1.00	2.00	1.00	1.50	1.00	1.00	1.50
Uvwie	2	1.00	2.00	1.50	1.50	1.00	1.50	2.00	2.00	1.50	1.00	1.50	1.00
Warri South-West	2	2.00	3.00	1.50	1.50	1.50	2.50	2.00	2.50	2.00	2.00	2.00	1.50
Warri South	1	2.00	3.00	3.00	2.00	2.00	2.00	3.00	2.00	3.00	1.00	2.00	2.00

5.2 Criteria weights

Actual weights extracted from experts are given in Table 2 and Figure 4. The normalized weights are shown in Table 3.

Table 2: Summary of weights (grouped median, mean and standard deviation) from experts for millennium development goals criteria

	Experts	Group 1 (GP1) Oil Comp	DPR	FMEn	Group 2 (GP2) Geol	Micro	Chem	Total Median (GP1)	Total median (GP2)	Mean	SD
MDGs											
WCE		4.57	3.83	4.25	4.17	4.50	4.60	4.33	4.43	4.32	0.30
IMH		3.67	4.00	4.00	3.50	3.67	4.50	4.09	4.00	3.89	0.36
UPE		4.00	4.00	4.50	4.14	4.25	4.00	4.15	4.23	4.15	0.20
PHR		4.83	4.00	4.33	4.20	5.00	4.50	4.40	4.54	4.48	0.38
YGI		3.50	3.00	3.67	3.60	4.33	3.00	3.40	3.50	3.52	0.50
GP		3.67	3.60	4.00	2.80	4.33	3.50	3.71	3.44	3.65	0.52
RIM		4.00	4.00	3.67	3.40	4.00	4.00	4.00	3.71	3.85	0.25
CCD		4.67	3.50	3.25	3.00	4.33	4.50	4.08	3.83	3.88	0.71
SFS		4.20	3.50	4.00	4.00	4.33	4.50	3.83	4.25	4.09	0.35
PE		3.80	4.00	5.00	3.50	3.50	4.20	4.23	3.86	4.00	0.56
MT		2.60	2.80	3.00	3.17	3.00	3.00	2.77	3.08	2.93	0.20
EES		4.40	3.17	4.50	3.20	4.00	3.75	3.90	3.55	3.84	0.57

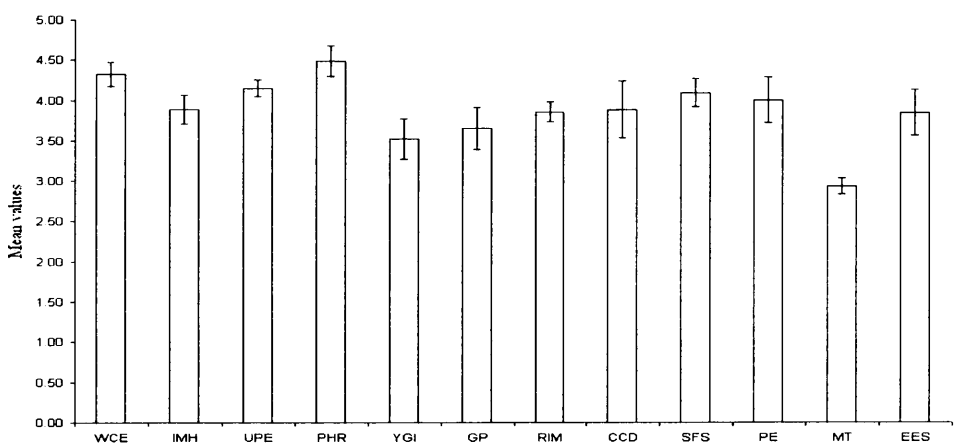

Figure 4: Mean and standard deviation values for Adaptive Capacity criteria

Table 3: Normalized weights for adaptive capacity for three different scenarios

Criteria	Code	Actual weights Scenario 1	Equal weights Scenario 2	50% for PHR Scenario 3
Wealth creation and Employment	WCE	0.093	0.083	0.045
Improved maternal health	IMH	0.083	0.083	0.045
Universal primary education	UPE	0.089	0.083	0.045
Poverty and hunger reduction	PHR	0.096	0.083	0.500
Youth/gender issue	YGI	0.076	0.083	0.045
Global partnership for development	GPD	0.078	0.083	0.045
Reduction in infant mortality	RIM	0.083	0.083	0.045
Combating common diseases	CCD	0.083	0.083	0.045
Shelter and food security	SFS	0.088	0.083	0.045
Power and energy	PE	0.086	0.083	0.045
Mass transportation	MT	0.063	0.083	0.045
Ensure environmental sustainability	EES	0.082	0.083	0.045

5.3 Ranking for alternatives

Table 4 and Figure 5 represent the calculated adaptive capacity index for the different local government areas

Table 4: Adaptive capacity index for local government areas in Delta State using the weighted summation method

LGA	Headquarters	Scenario A Actual weights	Scenario B Equal weights	Scenario C 50% for PHR
Aniocha North	Issele-Uku	1.74	1.73	1.78
Aniocha South	Ogwashi-Uku	1.89	1.89	1.94
Burutu	Burutu	1.52	1.54	1.45
Ethiope East	Isiokolo	1.72	1.72	1.64
Ethiope West	Oghara	1.88	1.89	1.79
Ika North-East	Owa Oyibo	1.82	1.82	1.70
Ika South	Agbor	1.79	1.79	1.74
Isoko North	Ozoro	1.95	1.95	1.88
Isoko South	Oleh	1.54	1.54	1.75
Ndokwa East	Aboh	1.58	1.58	1.77
Ndokwa West	Kwale	1.86	1.86	1.92
Okpe	Orerokpe	1.71	1.71	1.62
Oshimili North	Akwukwu-Igbo	1.67	1.69	1.49
Udu	Otor-Udu	1.67	1.67	1.59
Ughelli North	Ughelli	1.92	1.92	1.84
Ughelli South	Otu-Jeremi	1.76	1.76	1.60
Ukwani	Obiaruku	1.29	1.29	1.16
Uvwie	Effurun	1.46	1.46	1.48
Warri South-West	Ogbe-Ijoh	1.99	2.00	1.77
Warri South	Warri	2.26	2.25	2.14

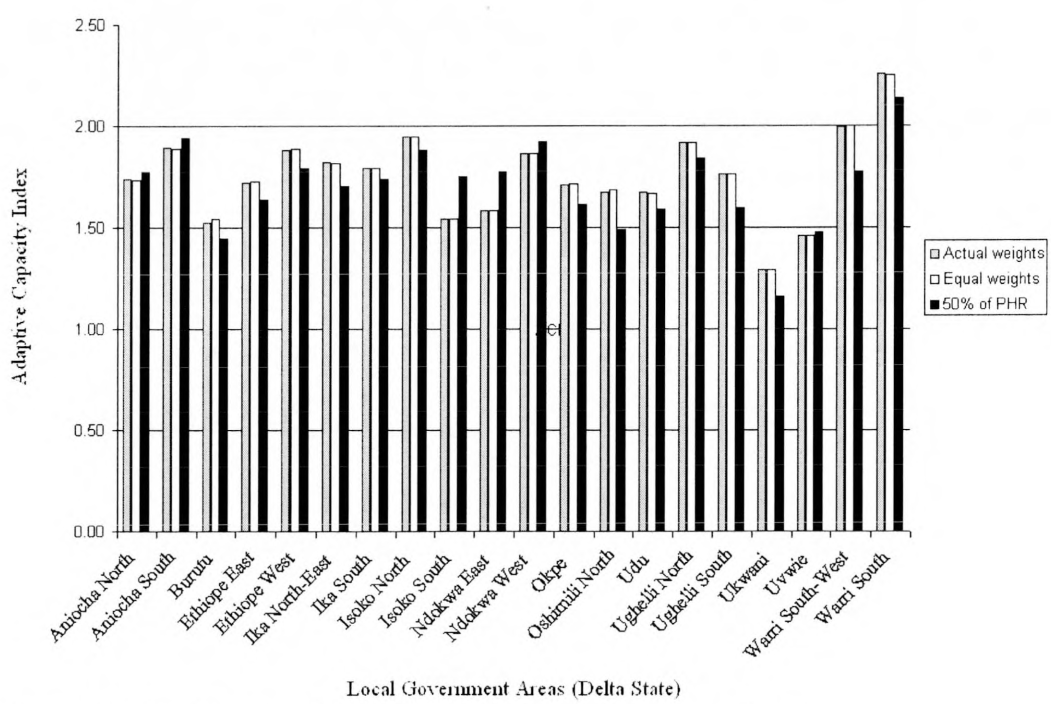

Figure 5: Adaptive capacity indices from three scenario analyses

6. DISCUSSION AND CONCLUSION

It has been seen that conflicts arise from different interests because of scarcity or depleted quality of resources (Torell 1997). The MCDA approach effectively integrates both quantitative and qualitative indicators within the multi-criteria framework. It shows that stakeholder views and values can be used in a rigorous framework which can be well understood by policy makers, regulators and planners. The approach has engaged a wide range of stakeholders and shows that participatory approaches can be used in conjunction with decision support tools such as the MCDA.

The drawbacks of this methodology included the difficulty of some of the stakeholders to understand some of the terminologies used in the questionnaire. Due to the unending crisis in the Niger Delta region, it was quite a daunting task to carry out the questionnaire survey. To overcome such problem, students from the crisis prone region were used to extract information from affected communities.

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ENVIRONMENTAL IMPACT ASSESSMENT OF SELECTED OIL PRODUCTION FACILITIES IN PARTS OF NIGER DELTA, NIGERIA

S.B. Olobaniyi* and O.O. Omo-irabor
Department of Geology, Delta State University, Abraka, P.M.B. 1, Nigeria
West African Coastal Management Initiative (WACMI)
sbolobaniyi@yahoo.com, omoomoirabor@yahoo.co.uk

Abstract
The impact of oil production activities on the chemistry of soil and groundwater was investigated around seven (7) production facilities, ranging from flow stations to wellhead in the western Niger Delta area. The method involved systematic sampling of soil and groundwater within a one kilometre radius of such facilities. The samples obtained were analysed for pH, TOC, TPH, V, Ni and Fe by standard procedures. The results indicate a general conformity of groundwater physico-chemistry to international standards for chemical potability. However, the investigated soil samples reveal in some cases elevated values of TPH (mean: 26.07mg/kg) and Ni (mean: 8.89mg/kg) which suggest a negative impact on the soil in the vicinity of such oil production facilities. Although groundwater may show no apparent contamination, pollutants trapped in the soil are in potential transit to groundwater, and may eventually be dissolved and transported through the soil profile to the water table by recharging rainwater. The environmental and health conditions of host communities are thereby endangered.

Keywords: Impact assessment, Production facilities, Soil, Groundwater, Niger Delta

1. Introduction

Nigeria is Africa's largest oil producing nation and ranks sixth in the world. Currently, Nigeria operates over 600 oil fields and in the process of granting more prospecting licences. However, the most important challenge confronting this industry is its inability to operate without significant degradation to the environment through soil, water and air pollution. Between the years 1976 and 1996, a total of 2,369,470 barrels of crude oil was estimated to have spilled into the environment (Nwilo and Badejo, 2006), causing significant negative impact on the ecosystem (Osuji and Nwoye, 2007), and eventually reducing the quality of life of the people. This among other factors has fuelled persistent agitation within the region, for a greater share from the central government, of the proceeds from oil.

Apart from major oil spills that occur along the pipelines predominantly through vandalisation, the aging operational facilities, including well heads and flow stations, constitute another, although a more subtle source of environmental contamination. Consequently, very little of their influence on the environment has been reported within the region. This paper examines aspects of the physico-chemistry of soil and groundwater in the vicinity of seven (7) oil production

* Corresponding author: S.B. Olobaniyi. Email – sbolobaniyi@yahoo.com

facilities within the western Niger Delta area and assesses the possible impact of such facilities on their environment.

2. Study Area

The seven studied facilities are all located in the following villages: Uzere, Igbide, Koko, Ologbo, Ozoro, Sapele and Afiesere, all within the western Niger Delta area (Fig. 1). The setting is generally rural, while agriculture is the main occupation of the dwellers. The vegetation type varies from mangrove swamp to rainforest although prolonged human interference has modified in places this natural environment, and is now being replaced by grassland and shrubs.

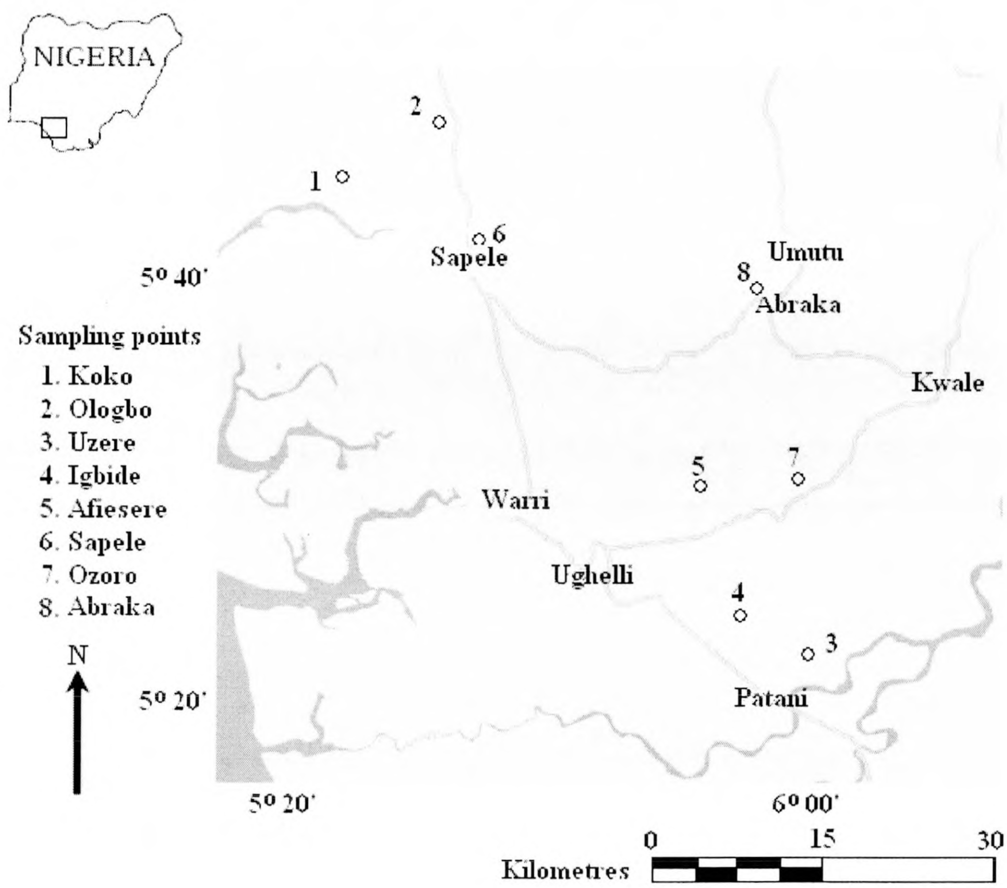

Figure 1: Map of Part of Western Niger Delta Showing Study Sites

The area is underlain by Cretaceous to Recent sedimentary sequences that constitute the Niger Delta. These sedimentary formations consist of fluviatile, marine and paralic sequences that are the sources and reservoir of hydrocarbon in the district. The topmost of these formations, usually the Coastal Plain Sands consists predominantly of continental loose sands and gravel with occasional clay intercalations (Olobaniyi el al., 2005)

3. Methodology

Five (5) topsoil and groundwater (well water) samples each were collected systematically within a one (1) kilometre radius of seven (7) oil production facilities and the control site (Abraka). Three (3) of these facilities were flow stations while four (4) were production wellheads. One (1) kilogramme soil sample was collected from each sampling point and stored in plastic bags. Replicate water samples were collected into one (1) litre plastic cans, one of which was acidified with HNO_3 for heavy metal analysis. Unstable parameters including temperature, dissolved oxygen (DO) and pH were measured in-situ. For the samples, total organic carbon (TOC), total petroleum hydrocarbon (TPH) and heavy metals (Ni, V, and Fe) were determined in the laboratory by standard procedures (ASTM, 2001).

4. Results

The mean values of the physico-chemical data generated for soil and groundwater from each facility is presented graphically and compared with that from a non-impacted area (Figures 2 and 3), whereas the statistical summary of all the mean values is presented in Table 1.

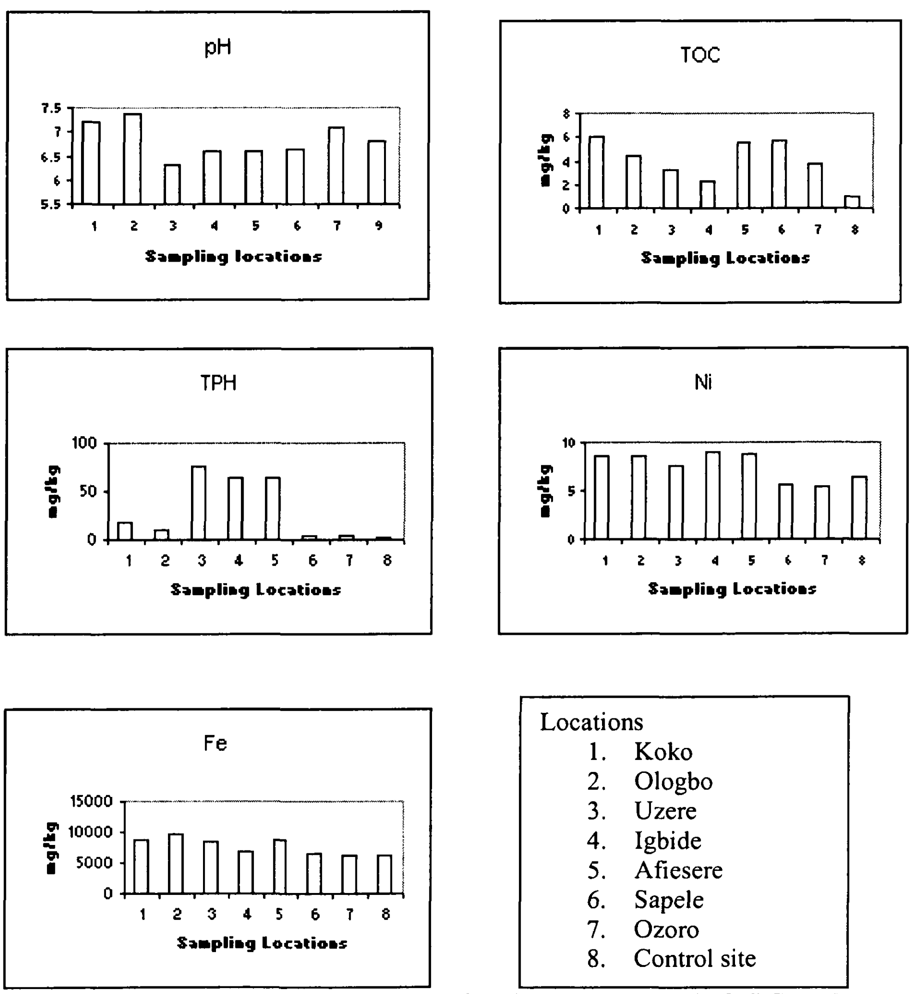

Figure 2: Average Values of selected physico-chemical Parameters in Soil Samples for the Study Locations

Soil samples show near neutral pH (6.30-7.37), generally low TOC (2.33-5.98 mg/kg) and a highly variable TPH (4.51- 76.68 mg/kg) reflected in high standard deviation (±30.93). V (<0.001 mg/kg) occurs below detection limit. However, Ni is slightly enhanced (5.34-9.10 mg/kg) compared to the control site. Fe (7009-9725 mg/kg) shows massively enhanced values in both study locations and control site, apparently reflecting the ferruginous nature of the soil.

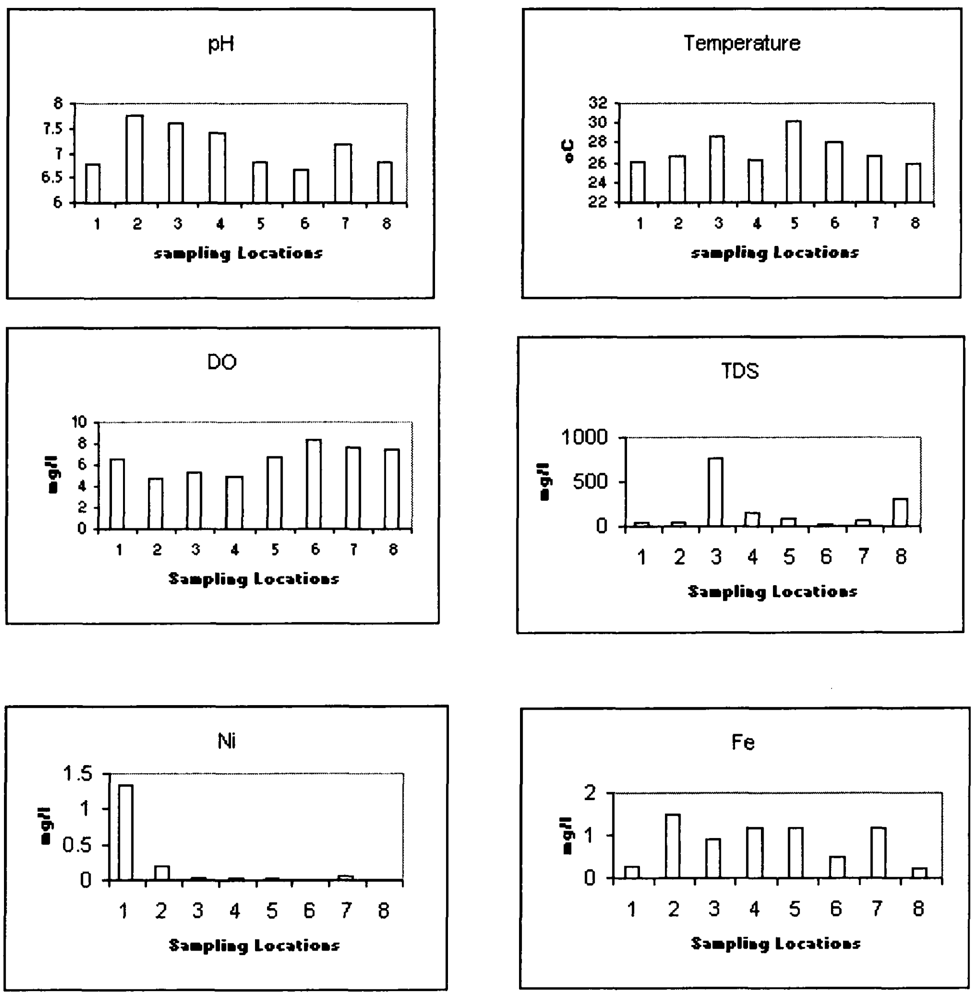

Figure 3: Average Values of selected physico-chemical Parameters in Groundwater Samples for the Study Locations

The water samples show pH (6.78-7.76) within the neutral range while DO values (4.99-7.63 mg/l) are moderate. TDS (35.6-752 mg/l) varies widely indicating varied levels of solute content in the water samples. V (< 0.001 mg/l) and Fe (0.28-1.48 mg/l) are low. Ni occurs in generally moderate amounts (Fig. 2) except around locations 1 and 2 where it exceeds the WHO (2006) specification (0.07 mg/l) for drinking water.

Table 1: Statistical Summary of Investigated Physico-chemical Parameters in Soils around the Production Facilities

n =35	Minimum	Maximum	Mean	Std. deviation
pH	6.30	7.37	6.83	± 0.39
TOC mg/kg	2.33	5.98	4.59	± 1.57
TPH mg/kg	4.51	76.68	26.07	± 30.95
V mg/kg	<0.001	<0.001	-	-
Ni mg/kg	5.34	9.10	8.89	± 1.33
Fe mg/kg	7009	9725	7667	± 2234

Table 2: Statistical Summary of Investigated Physico-chemical Parameters in Groundwater around the Production Facilities

n =35	Minimum	Maximum	Mean	Std. deviation
pH	6.67	7.76	7.18	± 0.47
Temp °C	26.2	30.2	27.57	± 1.55
DO mg/l	4.99	7.63	6.33	± 1.36
TDS mg/l	35.	35.6	168.37	± 282.68
V mg/l	<0.001	<0.001	-	-
Ni mg/l	0.02	1.34	0.24	± 0.53
Fe mg/l	0.28	1.48	0.96	± 0.46

5. Discussion

The result of this study indicates that elevated TPH values (>50 mg/kg) occurred in soils around 45 % of the facilities investigated. This is in excess of 20 mg/kg specified safe limit for oil and grease in soils in the region (DPR, 1991). Although the concentration of TPH was not determined in groundwater, the normal range of DO values recorded in the water samples imply that they have not been contaminated by hydrocarbon. This may be as a result of the filtering and sealing effects of the interstratified clays within the Deltaic Plain Sands and Benin Formation that underlie the area (Owoyemi and Olobaniyi, 2003). Such filtering capability of the soil probably produced the slight accumulation of Ni in the soil samples. Within the Niger Delta region, high hydrocarbon content in soils has been implicated in low soil fertility (Osuji and Nwoye, 2007) and plant toxicity (Baker, 1974; Amadi et al., 1993) and by implication low agricultural yield. Elsewhere, high cancer incidence has been linked to environmental contamination by hydrocarbons (Hurtig and Sebastian, 2002). With time, the trapped hydrocarbon, if not degraded, will get transported to the water table thereby endangering the health of the host communities.

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Mapping Nypa palm colonization of mangrove environments – potential for radar remote sensing in the Niger Delta

C. Paradzayi[1, 3 *] and O. Omo-Irabor[2]
[1] Department of Geography, Environmental Management and Energy Studies
University of Johannesburg
Auckland Park Kingsway Campus
Johannesburg, South Africa

* E-mail: cparadzayi@gmail.com

[2] Department of Geology
Delta State University
Abraka, Nigeria

[3] Department of Surveying and Geomatics
Midlands State University
Gweru, Zimbabwe

ABSTRACT

The mangroves of Nigeria are the largest in Africa and the third largest in the world after Indonesia and Brazil. The last twenty years has witnessed the rapid depletion of the mangroves by natural and anthropogenic processes. Natural factors include climatic perturbations, with its attendant effects on salinity and acidity, and coastal erosion and subsidence. Anthropogenic factors contributing to the degradation and depletion of the mangroves are mainly: crude oil activities and the invasion of the non-native Nypa palm (Nypa *fruticans*). The Nypa palm was first introduced in Calabar in 1906 and later in Oron in 1912 as an erosion control measure. The species rapidly established itself successfully and began colonizing the native mangrove vegetation. This invasive palm has resulted in general habitat conversion with resultant reduction in fish catch, poor navigation, ecological degradation and loss of biodiversity. However, the actual extent of this problem cannot be currently assessed due to limitations of current methods being employed. Previous attempts to use remotely sensed data have been limited by site specific methodologies making it difficult to apply such techniques to other mangrove regions. Field surveys are further hampered by the inaccessibility of mangrove environments due to flooding and tidal fluctuation in the Niger Delta region. Mapping the rate of invasion of the Nypa palm and extent of coverage from optical remote sensing techniques are limited by atmospheric conditions such as cloud and haze. Optical remote sensing is further complicated by the spectral similarities between mangroves and Nypa palm make it extremely difficult to differentiate the two species. This paper proposes to use synthetic aperture radar remote sensing for the rapid and cost-effective gathering, processing and analyzing the Nypa palm colonization of mangroves in the Niger Delta region. The method proposes the utilization of the backscatter characteristics of Nypa palm and mangroves to generate polarization signatures to discriminate the two species. The extent of Nypa palm invasion will then be mapped by using the polarization signatures to automatically extract Nypa palm colonies from the radar imagery. This is a

new and innovative approach that has not yet been tested in African mangrove environments.

Background

The Niger Delta is well known for its volatile socio-economic climate and contains about 25% of Nigerian population. There are several ethnic groups in the region with the Ijaws as the oldest, most complex and largest group (about 8 million in number). They occupy the whole of Bayelsa State and are also spread along the riverine areas of Rivers, Delta, Edo, Ondo and Akwa States (Uyigue and Ogbeibu 2007). The Ijaws are mainly riverine dwellers and derive the sources of livelihood from the aquatic ecosystem. Other ethnic groups occupying the region are the Ndoni, Degema, Egbema, Ogba, Ekpeye, Itsekiri, Urobo, Edo, Efik, Okpo, Growhia, and Ibibio.

The mangroves of Nigeria are the largest in Africa and the third largest in the world after Indonesia and Brazil (Blasco *et al.,* 2001). Occupying an area of 10,500km^2 within the Niger Delta region, the mangrove vegetation consists mainly of the *Rhizophora racemosa* (tall red mangrove) species (Niger Delta Environmental Survey 1997). The red mangrove with its unique stilt or prop roots covers over 90% of the area and can grow to a height of 45m under favorable conditions (CEDA, 1997). Other species include *Rhizophora mangle, Rhizophora harrisoni* and the short white mangrove *Avicennia Africana.*

The continuous exploration, production and transportation of crude oil over the last forty years with little regard for the environment has derived these group of people their mainstay. (Uyigue and Ogbeibu (2007) argue that people living in the Delta have resorted to vandalizing pipelines and other forms of social unrest to express their grievances over the destruction of their environment by multinational oil companies without adequate compensation.

Nypa colonization of mangroves

There has been a rapid depletion of mangrove environment in the Niger Delta by both natural and anthropogenic processes over the last couple of decades. Natural factors include climatic perturbations, with its attendant effects on salinity and acidity, and coastal erosion and subsidence (Diop *et al.*, 2002). Anthropogenic factors contributing to the degradation and depletion of the mangroves are mainly: crude oil activities and the invasion of the non-native Nypa palm (*Nypa fruticans*). The Nypa palm was first introduced in Calabar in 1906 and later in Oron in 1912 as a means to combat erosion. The species rapidly established itself successfully and in the process began colonizing native mangrove vegetation (CEDA, 1997). The nypa invasion has created environmental problems by reducing the firmness of the coastal sediments. Such invasions are also linked to general habitat conversion, leading to reduction in fish catch, poor navigation, ecological degradation and loss of biodiversity (Nigerian Conservation Foundation, 1996). However, it is currently difficult to assess the actual extent of nypa invasion due to limitations of current methods being employed.

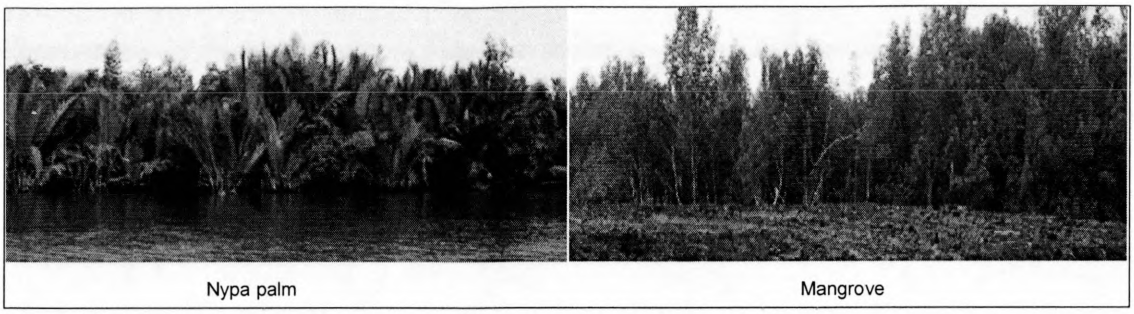

Figure 1 Nypa palm and Mangrove colonies

Problems with current mapping techniques

Precise and up-to-date spatial information on the current status of mangroves is a prerequisite for the sustainable conservation of mangrove ecosystems. Although field surveys are currently used to observe the proliferation of Nypa in the Niger Delta, it is extremely difficult to gather this information by using traditional field surveys because mangrove swamps are extremely difficult to access (Vaiphasa, 2006). The procedure is also laborious, time-consuming and, therefore, expensive (Hussin *et al.*, 1999). These problems are further compounded by the remoteness of some parts of the Niger Delta region and inaccessibility due to flooding and tidal fluctuation. As such, the use of ground-based methods to assess the invasion of the Nypa plant is almost impossible.

The proximity of the Niger Delta region to the equator implies very high cloud cover, with certain parts more or less under permanent cloud cover conditions through out the year. These conditions hamper the mapping of the extent of Nypa palm invasion from optical remote sensing techniques. Remote sensing provides an attractive means of obtaining vegetation data for defining deforested areas and updating management plans in mangrove areas. Optical remotely sensed imagery is well suited for capturing horizontally distributed conditions, structures and changes (Koch *et al.*, 2007; Patenaude, 2003) but is constrained by adverse atmospheric conditions such as clouds and haze (Hussin *et al.*, 1999), and in any case surveys only the upper surface of the vegetation canopy.

Previous studies to capture the occurrence of the Nypa palm include the 1997 Niger Delta Environmental Survey, which used the post-classification re-coding rule. The post-classification methodology used two sets of rules: one that revised a supervised Thematic Mapper (TM) classification, using plant species density/height only and another that used density/height and ecology to modify the classification, to reduce the confusion between mangrove and Nypa. Although is procedure helped to improve the distinction between mangrove and Nypa, the several variations of the post-classification do not make it globally applicable in other mangrove region. This is further complicated by the spectral similarities between mangroves and Nypa palm make it extremely difficult to differentiate the two species (Niger Delta Environmental Survey, 1997).

Potential of radar remote sensing for mapping Nypa colonies

The limitations of both the field surveys and optical remote sensing techniques calls for the adoption of more rapid and cost-effective methods for gathering, storing and analyzing the rate of nypa invasion in the Niger Delta. Radar remote sensing integrated into GIS offers one such viable alternative. Unlike optical systems, radar systems can be operated day or night and have an all weather capability. They can therefore penetrate clouds cover, fog, rain and atmospheric dust. Furthermore, radar energy has the ability to penetrate tree canopies and some surface features (Hussin *et al.*, 1999).

Polarimetry utilizes the differences in the shape, orientation and dielectric constant of transmitted and received radar signal to classify and extract parameters of natural targets. Improved assessment of tree heights and three-dimensional forest structural information can be obtained by coherently combining interferometry and polarimetry techniques with data from optical sensors for forests with mixed structural forms (Prakoso, 2006; Lucas *et al.*, 2006). This technique can be applied to map the extent of nypa palm invasion by studying the backscatter characteristics of the nypa palm and mangrove plants. The two plant species are phenologically different and thus are likely to give different backscatter characteristics. The differences in the polarization signatures will be used to classify radar images to discriminate the two different plant species. The areal extent of nypa invasion can then be ascertained.

Hussin *et al* (1999) have shown that mangrove deforestation caused by establishment of shrimp ponds can be detected on all optical and radar images. There is increased correlation between the signal polarization and incidence angle with the ability of particular radar sensors to detect changes in mangrove environments. Signal wavelength is critical in mapping vegetation species. HV polarization signal is transmitted in horizontal (H) and received in vertical (V) which allows capturing complete characteristics of vegetation covers (Rao and Gurusamy, 1990). Marghany *et al* (2006) have shown that LHV polarization is suitable band for mapping various vegetation species when using AIRSAR/POLSAR data. It has been proved that LHV band can penetrate from canopy level to land surface compared to C band (Proisy *et al.*, 2001). Data captured using this polarization state is able to discriminate species of coastal vegetation.

Concluding Remarks

Radar remote sensing has shown great potential in discriminating plant species in various biomes. The phenological characteristics of nypa and mangroves make this technique ideal for studying mangrove environments. However, this technology has not yet been tested in most African environment (tropics and subtropics). However, studies by Hussin *et al.* (1999) have shown that nypa plants can be identified from radar remote sensing data. Data from recently launched radar platforms such as ALOS PALSAR should be investigated for their capability to discriminate nypa palm from mangroves in the Niger Delta. This will provide quantitative data on the extent of nypa palm colonization of the mangrove areas. Management plans can then be formulated on the basis of empirical evidence and spatial temporal techniques can be employed to ascertain the rate of nypa invasion over time.

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A HYBRID IMAGE CLASSIFICATION APPROACH FOR THE SYSTEMATIC ANALYSIS OF LAND COVER (LC) CHANGES IN THE NIGER DELTA REGION

O. O. Omo-Irabor[a], K. Oduyemi[b]

Built and Natural Environment, School of Contemporary Sciences, University of Abertay, Bell Street. DD1 1HG, Scotland, UK

e-mail: [a]**0407276@abertay.ac.uk** [b] **K.Oduyemi@abertay.ac.uk**

KEY WORDS: Land cover, Supervised and unsupervised classification algorithms, Landsat images, Change detection, Accuracy assessment, Niger Delta

ABSTRACT:

The landscape of the Niger Delta region of Nigeria is undergoing rapid changes as a result of natural and anthropogenic activities. This necessitates the development of a rapid, cost effective and efficient land cover (LC) classification technique to monitor the biophysical dynamics in the region. Due to the intricate land cover patterns prominent in the study area and the irregularly indistinguishable relationship between land cover and spectral signals, this paper introduces a combined use of unsupervised and supervised image classification for detecting LC classes. The technique utilizes the spectral recognition of the unsupervised classification in the performance mode and the selection of sampling sites from a principal component analyzed image of the supervised classification in the training mode. The unsupervised and supervised classification algorithms used are the generalized form of Heckbert quantization and Maximum Likelihood (ML) respectively. With the continuous conflict over the impact of oil activities in the area, this work provides an initial basis of monitoring LC change, which is an important factor to consider in the design of an environmental decision-making framework. Landsat TM and ETM+ images of 1987 and 2002 were used to test the hybrid classification technique. The overall result indicates the ability to separate more LC classes. Furthermore, the approach provides a means of improving on the deficiencies of the unsupervised and supervised classification methods.

1. INTRODUCTION

The Niger Delta region, known as the economic mainstay of Nigeria is experiencing rapid changes resulting in the alteration of its fragile ecosystem. While the region embarks upon a rapid phase of economic expansion, it faces several environmental challenges caused partly by the pressures induced by anthropocentric activities through petroleum activities, economic development and demographic changes (Osei *et al*, 2006). The severity of the problem has been aggravated due to the absence of proper legislative, regulatory and institutional frameworks to tackle environmental degradation. There is the need to monitor such changes using remote sensing data which has the advantage of synoptic view, repetitive coverage, cost effectiveness and availability. The underlying premise for using remote sensing data is that a change in the status of an object must result in a change in radiance value (Mas, 1999).

Land cover classification and change detection have been conducted by Yang and Lo (2002), Mundia and Anyia (2005), using unsupervised ISODATA classification algorithm. In Nigeria, supervised classification has been used to monitor land use dynamics in south-western region (Akinyemi, 2005), while Ojigi (2006) compared different supervised classification algorithms to monitor landscape changes in Abuja. His findings reveal that the maximum likelihood algorithm performed better than the other methods used. During the last three decades, a large number of change detection methods have evolved that differs widely in refinement, robustness and complexity (Hall and Hay, 2003). These methods often involve change extraction and change classification and include, image overlay, image differencing, image ratioing, image regression, tassled cap transformation, chi-square transformation, post classification comparison and principal component analysis. Ridd and Liu (1998), from their study using some of the above mentioned algorithms, showed that there was no algorithm that had superiority over the others. Environmental change detection of the Niger Delta region using remotely sensed data has been conducted by Niger Delta Environmental Survey, (1997) using a post-classification change detection procedure, While (Osei *et al*, 2006; Omo-Irabor and Oduyemi, 2006), utilized results from unsupervised classification for detecting changes in the region.

Regular and up-to-date information on landscape change is required for planning and land use management, consequently, the need has arisen to develop a reliable methodology for monitoring the ever changing landscape of the Niger Delta region. This paper therefore, addresses the use of a hybrid classification method to detect changes that have occurred in the study area between 1987 and 2002.

2. STUDY AREA

The area selected for this study covers about 12,000km^2 of the Niger Delta region of Nigeria (Figure 1). It is located between latitudes 5° 15' and 6° 15' N and longitudes 5° 30' and 6° 30'E.

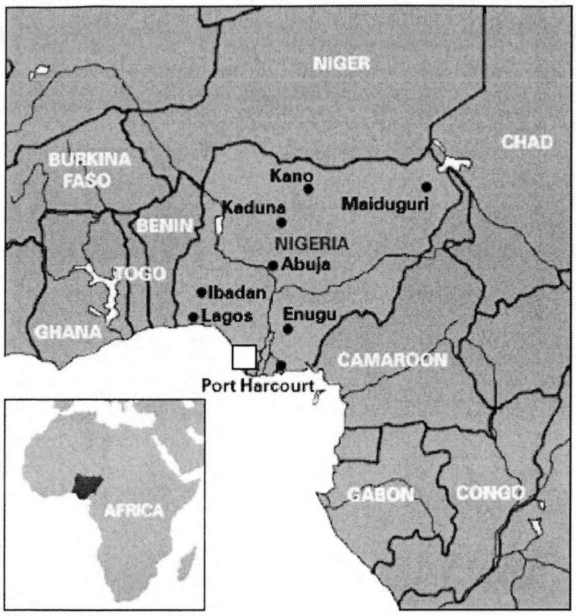

Figure1. Location of Study area

Four main surface geological units have been identified, consisting of: Fresh water swamp, Coastal Plain Sands, Mangrove swamps, and Sombreiro-Warri plains (Figure 2). Soils are generally hydromorphic and poorly drained. The pristine vegetation has been reduced considerably in the area and replaced by mosaic of secondary re-growth such as arable farmlands (cassava, maize and yam) and tree crops (oil palm, rubber, cocoa and plantain). The remaining natural vegetation occurs as fresh water swamp forest, mangrove swamp forest and ever green lowland rainforest a major source of timber. The River Niger is the major drainage system from which other discrete river systems originate. The region has a humid equatorial climate. The cloud cover is high, with relative humidity and average rainfall above 80% and 3000 mm respectively.

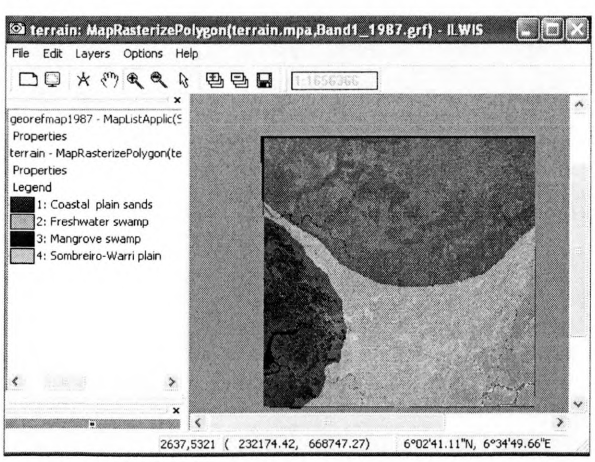

Figure 2: Major terrain units of study area

3. METHODS

3.1 Data sets and image pre-processing

The satellite images used in this study were obtained from the Global Land Cover Facility, (2005), consisting of one scene from the Worldwide Reference System (WRS-2) of path 189 and row 056 (Table 1). The bands used for the analysis include 1-5 and 7. ILWIS 3.3 software was used for image processing and GIS analysis.

Date of acquisition	Type of satellite image	Spatial resolution (m)
21-12-1987	Landsat-5 Thematic Mapper (TM)	30
28-12-2002	Landsat-7 Enhanced Thematic Mapper plus (ETM+)	30

Table 1. Satellite data used for digital image processing

Geometric correction of the images was already conducted producing positionally accurate orthorectified images having root mean square (RMS) geodetic accuracy of better than 50m (Tucker *et al*, 2004). Geocoding is essential for comparing spatially corrected maps of land cover changes through time. An affine transformation was used to rectify the 1987 TM image to the 2002 ETM+ using the UTM map projection (Zone 32), World Geodetic System 1984 datum (WGS 84) co-ordinate system. As the study area has relatively even terrain relief, only the first degree polynomial equation was required for image transformation. The nearest neighbour resampling method was used to avoid altering the original pixel values of the image data. The images were resampled to 28.5 m. The resultant root mean square error (RMSE) was about 0.5 pixels, indicating an excellent registration. According to Symeonakis *et al*, (2006), absolute pixel errors of more than one pixel can also be a cause of concern in multi-temporal studies.

Principal Component Analysis (PCA) was carried out to reduce the dimensionality of the data and improve the spectral information of the band combination. This aided in eliminating redundant information due to inter-band correlation (Lillesand *et al*, 2004). The first PC usually contains the largest amount of information from the original dataset and the transformation of the bands gives rise to a new coordinate system orthogonal to the previous. The calculated variance percentages per band for the images are displayed in Table 2.

	PCA 1(%)	PCA 2(%)	PCA 3(%)	PCA 4(%)	PCA 5(%)	PCA 6(%)
Image 1987	97.65	1.87	0.43	0.30	0.01	0.00
Image 2002	97.38	2.01	0.52	0.04	0.04	0.01

Table 2. Principal component analysis for 1987 and 2002 images

Constant cloud cover is a major problem hindering the use of remote sensing data in tropical regions. In order to improve the misclassification of land cover classes, clouds need to be eliminated from the image. The problems posed by their presence are two fold – firstly, they increase the land cover classes that have high spectral reflectance e.g. sediments and concrete structures. Secondly, they reduce the land cover classes they overlay on the image. Close inspection of the pixel values of the different bands showed that band 4 could be used to differentiate between cloud and other land cover classes effectively. The threshold digital value used for the differentiation was 95.

3.2 Classification system

Before any useful thematic information can be extracted from remote sensing data, a land cover classification system has to be developed to obtain the classes of interest to the analyst (Congalton, 1991). A combination of classification systems used by Forestry Management, Evaluation and Coordinating Unit (FORMECU) and Niger Delta Environmental Survey (NDES) gave rise to 7 land cover classes comprising of - built-up/exposed area, cultivated land, natural forest, water, mangrove (short), mangrove (tall) and palm forest. Within the context of this study, palm forest encompasses secondary growth, palm plantation and scrub.

3.3 Image Classification

The algorithms selected for land cover classification were the unsupervised – Heckbert quantization and supervised - Maximum Likelihood classification algorithms.

3.3.1 Unsupervised Classification

The unsupervised or clustering classification algorithm used is the generalized form of Heckbert quantization. Clustering is the process of identifying pixel possessing the same spectral characteristics. Heckbert quantization is a median cut clustering algorithm that groups image data into spectral clusters based on the statistical properties of all pixel values. TM bands 1, 4 & 5 and ETM+ bands 1, 2 & 5 were used for the three-band combination based on the calculated Optical Index Factor (OIF) of 35.68% and 37.37% respectively. The OIF value is based on the amount of total variance and correlation within and between various band combinations (Jensen, 2005).

This algorithm first builds a three dimensional histogram from the input bands. The histogram representing the feature space is split into many boxes depending on the number of cluster required. Then, appropriate colors are assigned to represent each cluster. The number of clusters used is very important as the number affects the ability of the algorithm to spectrally separate clusters. If the number of clusters selected is small too spectral mixing among land cover classes is obtained and if large, very pure clusters will be generated. To determine the best possible number of clusters to use, different numbers were attempted to spectrally separate classes such as 10, 20, 40, and 50. 50 clusters were finally arrived at as it provided a reasonable separation of the different land cover classes.

3.3.2 Supervised Classification

Maximum likelihood is the most commonly used supervised classification and is it based on the assumption that the training data statistics in each band are normally distributed. Supervised classification begins with defining the areas that will be used as training sites for the different land cover classes. A prior labelling of pixels is then performed on the selected training sites. To avoid the problem of linearity caused by similarity among spectral bands, the first three results from principal component analysis (PCA 1, PCA 2 and PCA 3) were used as band combination for the purpose of creating sample sets.

3.4 Image reclassification

Preliminary examination of the classified images using the two algorithms revealed a wide range of spectral confusion among land cover types. Spectral confusion refers to the fact that several land cover classes have similar spectral response and this poses a major problem of classification inaccuracy (Yang and Lo, 2002). To reduce this problem, close inspection of the classes was executed to highlight major areas of misclassified land cover. This was achieved with the aid of vegetation/land use maps and local knowledge. Most water pixels were classified as mangrove even outside the boundaries of the mangrove swamp. Therefore, to improve on the classification of water, mangrove and water clusters in the unsupervised images were all grouped as water. A resultant attribute map was created for water class only. Additionally, an attribute map was made for natural forest clusters as they were well discriminated from other land cover types in the unsupervised classification especially within the Coastal plain sands. The study area was then sub-divided into 2 main terrain units, whereby the mangrove swamp was separated from the other three terrain units. The attribute maps were then incorporated into to supervised classified maps with the aid of conditional statements. Majority of built-up/exposed areas was separated from other land cover classes especially cultivated by the Normalized Difference Built-up Index (NDBI) (Zha *et al*, 2003).

$$NDBI = \frac{MidIR_{TM5} - NIR_{TM4}}{MIdIR_{TM5} + NIR_{TM4}} \quad (1)$$

$$Built-up_{area} = NDBI - NDVI \quad (2)$$

A threshold value of 0.1 was applied to separate Built-up areas from other land cover classes. Smoothening of the classified images to remove the salt and pepper appearance was achieved using a 3x3 majority filter. The reclassified images are shown in Figure 3.

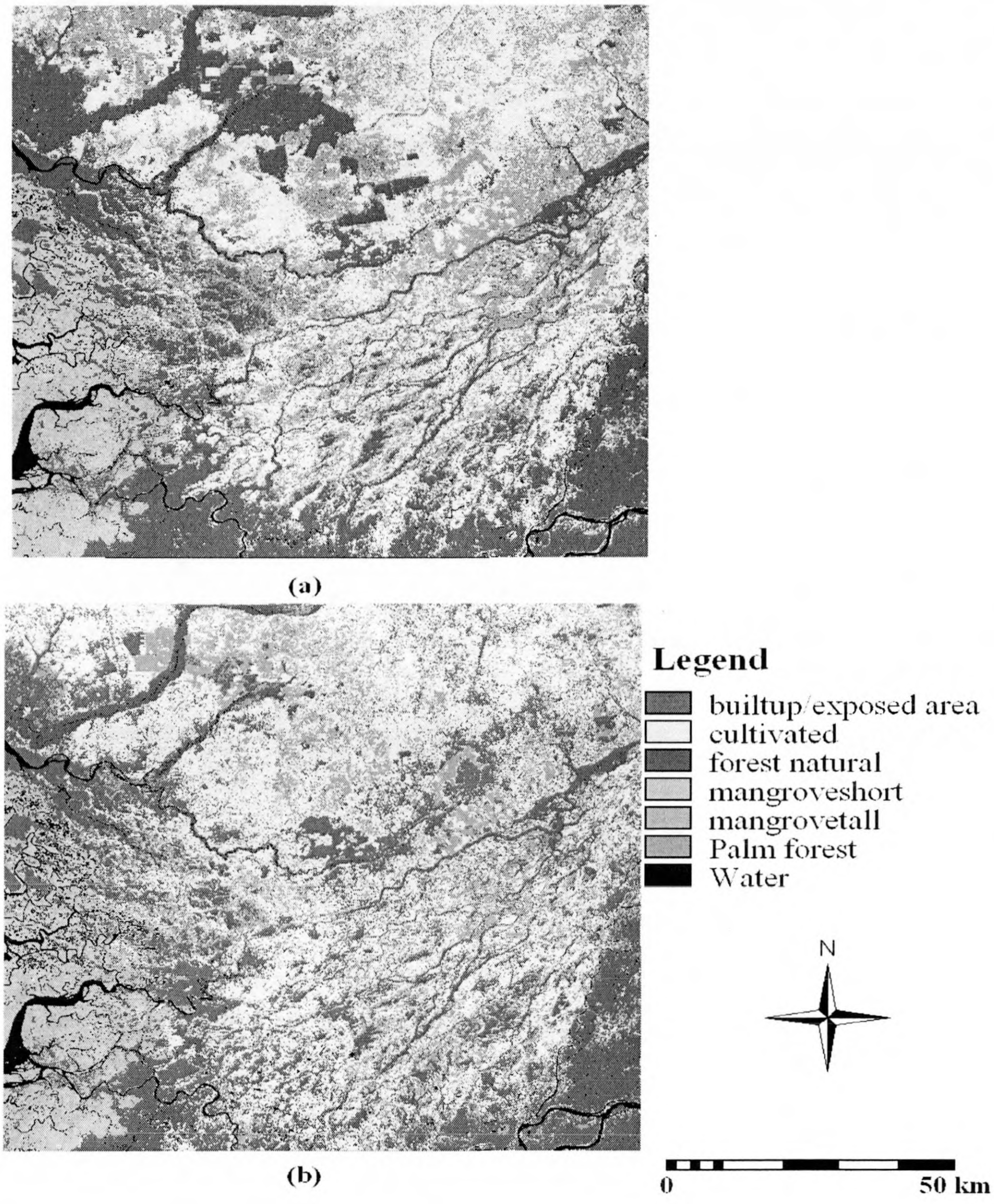

Figure 3. Classified images (a) Landsat TM 1987 (b) Enhanced Thematic Mapper plus (ETM+) 2002

3.5 Land cover classification accuracy assessment

Classification accuracy is necessary to establish the performance of derived thematic map with ground truth or other reference data set. The confusion matrix is the most frequently used way of expressing classification accuracy. Information in the confusion matrix is evaluated using univariate (e.g. producer's, user's and overall accuracies) (Jensen, 2005).

Digital vegetation and land use maps prepared by the Nigerian Forestry Management, Evaluation and Coordinating Unit (FORMECU) and Niger Delta Environmental Survey (NDES) were used for verifying the accuracy of the classified Landsat TM 1987 image. The verification data for the 2002 classification were biased due to the inaccessibility of majority of the region. Sampling was therefore executed close to roads during field visits in 2006 with the aid of GPS.

3.5 Change detection

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Successful use of satellite remote sensing for land cover change detection depends upon an adequate understanding of landscape features, imaging systems, and information extraction methodology employed in relation to the aims of analysis (Yang and Lo, 2002). The selection of an appropriate change detection algorithm is essential because it has a direct impact on the type of classification to be performed and whether important change information can be extracted from the image (Jensen, 2005). A post classification change detection method was applied. Although the accuracy of post-classification methods is dependent on the accuracy of the individual classifications and is subject to error propagation, the classification of each date of imagery builds a historical series that can be more easily updated and used for applications other than change detection (Yuan *et al*, 2005). Also, this method avoids the problems that arise due to variation in sensor characteristics, atmospheric effects, solar illumination angle sensor view angle and vegetation phenology between dates since each image is independently classified (Chen *et al* 2005).

4. RESULTS AND DISCUSSION

The results of the hybrid classification method for the 1987 and 2002 images are shown in Tables 3 and 4 respectively. The overall accuracy assessment of the 1987 and 2002 images are 83.03% and 76.16% respectively. The misclassification of palm forests affected the accuracy assessment of both 1987 and 2002 images. This could be due to the presence of some amount of palm trees in all land cover classes in the region with the exception of water bodies. The hybrid classification approach in conjunction with NDBI aided the improved performance of built-up/exposed areas, water and natural vegetation.

Land cover classes	BE	CL	NF	MT	MS	PF	W	Total	User's accuracy (%)
Built-up/exposed areas (BE)	183							183	100
Cultivated land (CL)	9	318				27		354	90
Natural forest (NF)			296			127		423	70
Mangrove (tall) (MT)				99	9		2	110	90
Mangrove (short) (MS)			1		117			118	99
Palm forest (PF)	28	82	7			49		116	30
Water (W)							108	108	100
Total	220	400	304	99	126	203	110	1462	**Overall accuracy 83.03%**
Producer's accuracy (%)	83	80	97	100	93	24	98		

Table 3. Confusion matrix for 1987 image

Land cover classes	BE	CL	NF	MT	MS	PF	W	Total	User's accuracy (%)
Built-up/exposed areas (BE)	46	0	0	0	0	0	0	46	100
Cultivated land (CL)	0	49	0	0	0	2	0	51	96
Natural forest (NF)	0	3	25	0	0	0	0	28	89
Mangrove (tall) (MT)	2	0	2	14	6	0	0	24	58
Mangrove (short) (MS)	0	0	5	0	17	0	0	22	77
Palm forest (PF)	1	7	22	0	0	11	0	41	27
Water (W)	0	2	0	0	0	0	11	13	85
Total	49	61	54	14	23	13	11	225	**Overall accuracy 76.17%**
Producer's accuracy (%)	92	80	48	100	74	85	100		

Table 4. Confusion matrix for 2002 image

Cultivated land occupies more than a third of the total land areas in both years (Figure 5). The mainstay of majority of the rural dwellers in the upland region is farming. Since the post classification accuracy is dependent on the initial accuracies of the classified images, this gives a reduced accuracy of 63.24%. The greatest depletion of land cover occurred in Natural forest. An amount of 9.21% equivalent to 1113.00 km^2 of natural forest disappeared within the 15year period. This result is in line with Osei *et al*, (2006), that forest estate of only about 10 million hectares (10 percent of total land area of Nigeria) is declining at a rate of 3.5 percent annually. The main factor responsible for this decline can be attributed to logging activities especially in the upland regions. Palm forest comprising mainly of secondary growth, scrub and palm plantations experienced the second largest decline of 7.07% (853.8 km^2), arising from the demand for cultivated lands. All other classes showed increase in cover change, with built-up/bare areas and cultivated areas increasing by 10.62% (1282.73 km^2) and 5.28% (637.9 km^2) respectively. Water bodies increased by 6.7%, this is attributed to the classification of shadow as water bodies in the 2002 image. The increase in short mangrove may be due to the colonization of a wild tree species known as Nypa (Niger Delta Environment Survey, 1997). This species is difficult to distinguish from mangrove on satellite images.

Land cover classes	1987 image		2002 image		Change	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	(km^2)	(%)
Built-up/exposed areas	459.1	3.80	1741.8	14.42	1282.7	10.62
Cultivated land	4217.3	34.90	4855.2	40.18	637.9	5.28
Natural forest	3462.8	28.66	2349.7	19.45	1113.0	-9.21
Mangrove (tall)	549.3	4.55	471.3	3.90	78.0	-0.65
Mangrove (short)	501.9	4.15	523.1	4.33	21.1	0.17
Palm forest	2621.5	21.70	1767.7	14.63	853.8	-7.07
Water	270.4	2.24	373.5	3.09	103.1	0.85
Total	12082.3	100	12082.3	100		

Table 5. Change of land cover classes between 1987 and 2002

5. CONCLUSION

The purpose of this work was to develop a rapid method of producing temporal land cover maps for change detection analysis. By combining the results from the two algorithms with knowledge of terrain characteristics, in such a way that only areas that gave acceptable results were combined and used for further analysis, the problem of spectral confusion was significantly reduced in some land cover types such as water, natural forest and mangrove. Although the performance of this hybrid approach improved discrimination of land cover types especially in the upper section of the study area, the misclassification of palm forests affected the accuracy assessment of both 1987 and 2002 images.

This paper also revealed the importance of temporal and spatial remote sensing data and GIS tools in detecting the degradation of the environment from development activities in the region. The depletion of forest and mangrove can be attributed to logging, creation of land for farming and oil activities. While the presence of oil companies in the region has attracted labour thus increasing urbanisation. In the absence of an alternative rapid and cost-effective means of obtaining landscape information for monitoring the constant changing, this systematic approach becomes necessary although it needs to be continuously revised, as other techniques for improving the accuracy of remote sensing data are developed.

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AFRICA'S DEVELOPMENT

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A COMPARATIVE STUDY OF CLASSIFICATION METHODS FOR MONITORING LAND USE LAND COVER (LULC) CHANGES USING REMOTE SENSING TECHNOLOGY AND GIS TECHNIQUES

O. O. OMO-IRABOR and ODUYEMI K.
School of Contemporary Sciences, University of Abertay, Bell Street. DD1 1HG, Scotland, UK
e-mail: 0407276@abertay.ac.uk

KEY WORDS: Land use/land cover; Niger Delta; Landsat images; Remote sensing; Supervised ISODATA classification; Unsupervised maximum likelihood classification

ABSTRACT:

The landscape of Delta State, Nigeria is undergoing accelerated changes directly linked to oil exploration, exploitation and production activities transcending over forty years. Although these activities generate over 90% of Nigeria's revenue, they have resulted not only in the degradation of the ecosystems but also posing hazards to human health and polluting water resources. With the continuous conflict over the impact of oil activities in the area, land use/land cover (LULC) classification and change detection are important factors to consider in the design of an environmental decision-making framework. This gives a better understanding of the actual impact of various human activities for the resolution of conflicts by policy makers.

This study was conducted to develop a systematic methodology for detecting changes from satellite data. Secondly, this study compares two parametric techniques, unsupervised ISODATA and supervised maximum likelihood (ML), to classify LULC and investigate the extent of environmental changes impacted by human activities in the region. Landsat TM and ETM+ images spanning the period of fifteen years (1987 to 2002) were used to assess LULC changes in parts of the Niger Delta region of Nigeria. The results reveal the pros and cons of the two methods and the effects of their overall accuracy on post-classification change detection.

1. INTRODUCTION

The Niger Delta region of Nigeria has experienced accelerated changes induced by natural and anthropogenic disturbances. Prior to the discovery of crude oil in 1954, the region was popular for agriculture and forestry. Industrialization particularly linked to ongoing oil exploration and exploitation activities transcending over forty years, has created jobs and attracted people from home and abroad. The exploitation of these resources has left its toil on the region. Changes arising from oil activities such as deforestation, urban areas alteration can be detected using remotely sensed data. The underlying premise for using remote sensing data is that a change in the status of an object must result in a change in radiance value (Mas, 1999; Hall and Hay, 2003; Al-Quraishi et al, 2004).

Land cover classification and change detection have been conducted by Yang and Lo (2002), Mundia and Anyia (2005), using unsupervised ISODATA classification algorithm. In Nigeria, Ojigi (2006) compared different supervised classification algorithms to monitor landscape changes in Abuja. His findings reveal that the maximum likelihood algorithm performed better than the other methods used. Environmental change detection of the Niger Delta region using remotely sensed data has been conducted by Niger Delta

Environmental Survey, (1997), Osei et al, (2006), Adegoke and Akinyede (2006). They reported LULC decline particularly in the mangrove and forest areas while agricultural land and built-up areas increased.

Remote sensing deals with the knowledge and techniques used to analyse, interpret, monitor and manage environmental changes, using optical and microwave imagery from various kinds of sensors (Kabanza et al, 2001). Remote sensing capability is enhanced, by being a component of Geographic Information Systems (GIS). These systems are powerful sets of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough and McDonnell, 2000). Given the spatial nature of oil pollution, GIS provides an integrative tool for the generation, storage and presentation of relevant information. It can be further utilized in assessing the impact of crude oil pollution through the interaction of a database with various environmental indices. This paper compares two parametric classification algorithms in estimating the changes that have occurred in the study area between 1987 and 2002. The research approaches the use of remote sensing data from their ability to discriminate changes in the environment as a result of natural and anthropogenic activities.

2. STUDY AREA

The area of interest lies within latitudes 5° 10′ 39″ - 5° 41′ 19″N and longitudes 5° 35′ 59″ - 6° 06′ 09″E and is contained in the triangle of Niger Delta region of Nigeria (Figure 1). Its geology is the product of both fluviatile and marine sediment build-up during the upper Cretaceous. Three major depositional cycles have occurred in the region leading to the deposition of the Akata, Agbada, and Benin Formations. The Agbada Formation is rich in hydrocarbon. The relief is low lying and built on the successive sedimentation of four physiographic units - fresh water swamp, mangrove swamp, coastal plains and the upland Niger valley. Soils are generally hydromorphic and poorly drained.

The pristine vegetation has been reduced considerably in the area and replaced by mosaic of secondary regrowth such as arable farmlands (cassava, maize, yam) and tree crops (oil palm, rubber, cocoa, plantain). The remaining natural vegetation but they still occur as fresh water swamp forest, mangrove swamp forest and ever green lowland rainforest a major source of timber. The River Niger is the major drainage system from which other discrete river systems originate. The region has a humid equatorial climate. The cloud cover is high, with relative humidity and average rainfall above 80% and 3000mm respectively.

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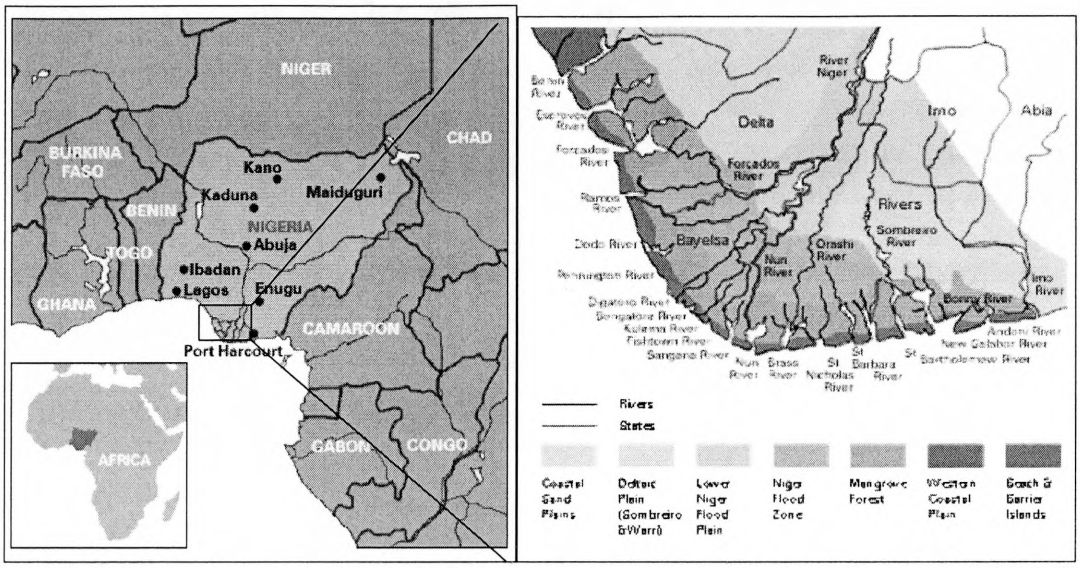

Figure 1. Map of Niger Delta region

3. DATA SETS

The satellite images used in this study consist of one scene from the Worldwide Reference System (WRS-2) of path 189 and row 056. Orthorectified images of Landsat-5 Thematic Mapper (TM) and Landsat-7 Enhanced Thematic Mapper plus (ETM+) acquired on the 21-12-87 and 28-12-2002, respectively. The images were obtained form Global Land Cover Facility (GLCF). The bands used for the analysis include 1-5 and 7. Bands 2, 4 and 7 were used to make the colour composite as the combination gave the closest natural colour composite. Geometric correction of the images was already done using the UTM map projection using, World Geodetic System 1984 datum and WRS 84 ellipsoid. The final orthorectified images produced accurate images having root mean square (RMS) geodetic accuracy of better than 50m (Tucker et al, 2004). Subsets from the original scene were then extracted for the two images for further analysis. Digital map containing land use/land cover information was used to select test data for the Landsat TM 1987 and Landsat ETM+ 2002 image classification. Additionally test data for the Landsat ETM+ 2002 classification were acquired from field visit with the aid of GPS.

4. METHODS

4.1 Development of classification system

Before any useful thematic information can be extracted from remote sensing data, a LULC classification system has to be developed to obtain the classes of interest to the analyst (Congalton, 1991). A number of classification systems already exists for LULC, they include the U.S. Geological Survey Land-Use/Land Cover Classification System (Anderson et al, 1976), Coordination of Information on the Environment (CORINE) land cover (European Environment Agency, (2000), and Food and Agriculture Organization (FAO) land cover classification system (LCCS) (Jansen and Di Gregorio. 2003). While land cover refers to the type of material present on the landscape, land use on the other hand is what is done on the land (Jensen, 2005).

Since there are already in existence reputable classification systems, such as those listed above, it would be meaningless to develop a system that would be useful only for the purpose of this research. The commonly used U.S. Geological Survey Land-Use/Land Cover Classification System (Anderson et al, 1976) was thus modified for the preparation of the legend for the LULC maps. Since 30m resolution images were used for the classification, the following 6 land use/land cover classes were derived; built-up/bare area, agricultural land, forest, wetland, water and sediments.

4.2 Image classification

Selection of the most appropriate algorithm for land cover classification from satellite data will depend on specific circumstances and available resources (DeFries and Chan, 2000). The unsupervised – ISODATA and supervised - maximum likelihood classification algorithms were used for this analysis. For the unsupervised classification, the Multispec software Windows NP/XP version 3.1 was used. It is a processing system for interactively analyzing Earth observational multispectral image data such as that produced by the Landsat series of Earth satellites and hyperspectral image data from current and future airborne and spaceborne systems (Multispec, 2006). The ILWIS software version 3.3 was used for supervised classification and GIS analysis.

4.2.1 Unsupervised ISODATA Classification

Unsupervised algorithms often attempt to find groups or clusters in data that are spectrally similar. The basic assumption in unsupervised classification is that values with a given cover type should be close together in the measurement space, whereas data in different classes should be comparatively well separated (Lillesand et al, 2004). The resulting clusters do not necessarily have any relationship with the classes of informational value they only assist in obtaining a list of classes that are exhaustive. Therefore, the results of the classification must be compared to some reference data for meaningful interpretation. The Iterative Self-Organising Data Analysis Technique (ISODATA) clustering algorithm is a modification of k-means clustering algorithm (Jensen, 2005). It uses minimum spectral distance to assign a cluster for each potential pixel.

The number of classes is the most significant of the clustering parameters (Yang and Lo, 2002). If too small, relatively broad clusters may be generated which may not produce true results. If the number is too big, very pure clusters may be yielded with highly demanding computational resources and substantial increase in time required for cluster labelling (Mundia and Aniya, 2005). The final number of classes chosen for this study was 40. The other required parameters include the maximum percentage of pixels whose class values are allowed to remain unchanged between iterations and the minimum cluster size. 99% and 7 were chosen for convergence value and minimum cluster size respectively. A value of 100 was selected as the threshold value. This implies that the system is forced to assign every pixel in the image to one of the clusters. A value of less than 100 results in some pixels not being assigned to clusters (Multispec, 2001). The classification result arranges and assigns clusters in order of descending level of brightness. Lastly, a true colour scheme resembling that of the original image was then used to assign colour to the different classes with the aid of digital vegetation, land use maps and ground truth data.

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4.2.2 Supervised maximum likelihood classification

Maximum likelihood is the most commonly used supervised classification and is it based on the assumption that the training data statistics in each band are normally distributed. It considers the distances towards class means and calculates the variance-covariance matrix of each class. Supervised classification begins with defining the areas that will be used as training sites for the different land cover classes. Training vectors must be at least unimodal and must not exhibit multicollinearity (Currit, 2005). They also require a large training data set which can be very costly and generally not possible to add incrementally to the training data while training the classifier. A minimum of 15 samples was selected for each class. Ideally, the number of pixels selected should be more than 10 times as many pixels as there are bands in the image to be classified (Jensen, 2005). This was made with several training sites for the more training site selected, the better the results gained. The display of feature space using bands 2 and 3 aided in the discrimination of pixels for the different classes.

5. RESULTS AND DISCUSSION

Figure 2 shows the results of unsupervised ISODATA and supervised maximum likelihood classification for Landsat TM 1987 and ETM+ 2002. A comparison of the classified images reveals that the unsupervised ISODATA algorithm performed better than the maximum likelihood as it gave a close semblance to the LULC map used for the. The accuracy assessment of the unsupervised 1987 and 2002 maps gave over all accuracy of 61.29% and 69.33% respectively. The low values were as a result of misclassification between built-up/bare areas and forest in the 1987 image, while the misclassification between wetland and shadow affected the 2002 image. Since the post classification accuracy is dependent on the initial accuracies of the classified maps, this implies a reduced accuracy using the maximum likelihood algorithm. The classified maps derived from ISODATA were therefore used to compute the changes for the different LULC categories.

Table 1 shows the total LULC change between 1987 and 2002 using the ISODATA algorithm. The greatest change of 30.9% equivalent to 34,414ha of forest disappeared within the 15 year period. Wetland, made up of mainly Mangrove experienced the second decline of 6.2% (1637 ha). Shadow in the 2002 image was misclassified as wetland, thus giving an erroneous estimate. All other classes showed increase in cover change, with sediments topping the group with 17% (190.4 ha). The presence of clouds increased the amount of sediments in the 2002 image. Built-up/bare areas and agricultural land increased by 12.3% (4108.1 ha) and 12.1% (16411.1 ha) respectively. Water bodies increased by 6.7%, this could be attributed to the classification of shadow as water bodies in the 2002 image.

LULC classes	Area of 1987 (ha)	Area of 2002 (ha)	Change (%)
Agricultural land	118834.8	135245.9	12.1
Built-up/bare areas	29178.9	33287.0	12.3
Forest	145940.2	111525.8	-30.9
Wetland	28016.2	26379.0	-6.2
Water	11115.6	11914.1	6.7
Sediment	928.4	1118.8	17.0

Table 1 Percentage change for LULC classes between 1987 and 2002

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6. CONCLUSION

This paper presents the applications of two parametric classification algorithms in monitoring land use and land cover changes. The ISODATA algorithm performed better than the maximum likelihood as it was able to discriminate between the different land cover classes. Since they both have their limitations, it is therefore recommended to utilize both during image analysis techniques bearing in mind their strengths and weaknesses. Further research will therefore be carried out in the study area using a hybrid method that incorporates both algorithms. More reference data is required to improve the post-classification results. This paper also revealed the importance of temporal and spatial remote sensing data and GIS tools in detecting the degradation of the environment from development activities in the region. The depletion of forest and mangrove can be attributed to logging, creation of land for farming and oil activities. While the presence of oil companies in the region has attracted labour thus increasing urbanisation.

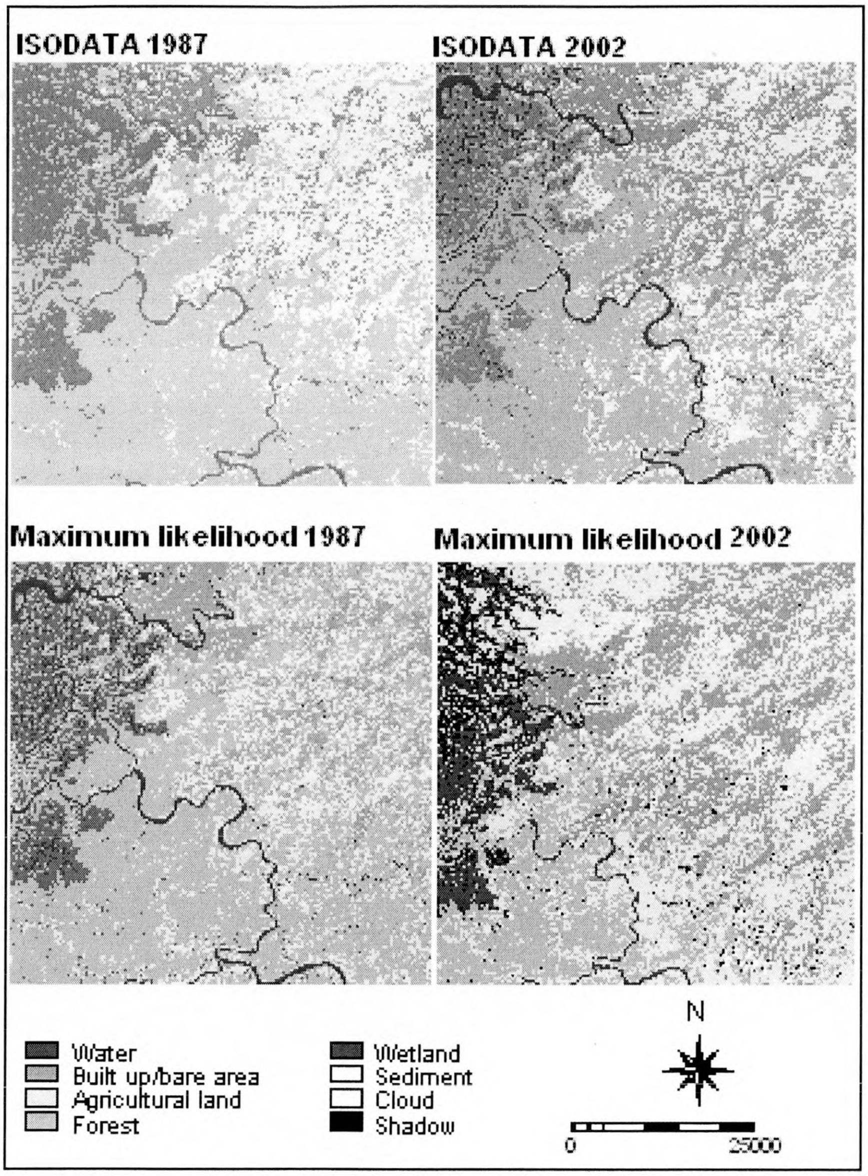

Figure 2 Unsupervised and supervised classification for 1987 and 2002 images

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